PB82-102492

Granular Activated Carbon Installations

Culp/Wesner/Culp
Cameron Park, CA

Prepared for

Municipal Environmental Research Lab.
Cincinnati, OH

Sep 81

U.S. Department of Commerce
National Technical Information Service
NTIS

EPA-600/2-81-177
September 1981

PB82-102492

GRANULAR ACTIVATED CARBON INSTALLATIONS

by

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CINCINNATI, OHIO 45268

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NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/2-81- 177	**2.** ORD Report	**3. RECIPIENT'S ACCESSION NO.** PB82 10249 2
4. TITLE AND SUBTITLE Granular Activated Carbon Installations		**5. REPORT DATE** September 1981
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Russell L. Culp, Justine A. Faisst, and Clinton E. Smith		**8. PERFORMING ORGANIZATION REPORT NO.**
9. PERFORMING ORGANIZATION NAME AND ADDRESS Culp/Wesner/Culp, Consulting Engineers Cameron Park, California		**10. PROGRAM ELEMENT NO.** PE# BNC1A
		11. CONTRACT/GRANT NO. CI-76-0288
12. SPONSORING AGENCY NAME AND ADDRESS Municipal Environmental Research Laboratory - Cin., OH Office of Research and Development U.S. Environmental Protection Agency Cincinnati, Ohio 45268		**13. TYPE OF REPORT AND PERIOD COVERED** Final and Interim
		14. SPONSORING AGENCY CODE EPA/600/14

15. SUPPLEMENTARY NOTES

Project Officer - Robert M. Clark (513) 684-7488

16. ABSTRACT

This report complies and summarizes design criteria, performance data, and cost information from twenty-two operating granular activated carbon (GAC) installations. These plants produce municipal water for drinking, treat municipal and industrial wastewaters, and process food and beverage products. It provides guidance in estimating the cost of GAC treatment for public water supplies. The manual is intended for use in connection with a previous series of EPA reports on "Estimating Water Treatment Costs" to obtain project-specific cost estimates. This manual is not a design manual. Rather, it describes how to obtain design criteria for water systems.

This report was submitted in fulfillment of Contract No. CI-76-0288 by Culp/Wesner/Culp under the sponsorship of the U.S. Environmental Protection Agency, and work was completed as a January, 1981.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Economic Analysis; Environmental Engineering; Operating Costs; Water Treatment; Water Supply; Cost Estimates	Safe Drinking Water Act; Unit Processes; Treatment Efficiency; Granular Activated Carbon	13B

18. DISTRIBUTION STATEMENT Release to Public	**19. SECURITY CLASS** *(This Report)* Unclassified	
	20. SECURITY CLASS *(This page)* Unclassified	**22. PRICE**

EPA Form 2220-1 (Rev. 4-77)

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communications link between the researcher and the user community.

This report presents data on the cost and operation of existing granular activated carbon installations for water and wastewater treatment which may be useful in the planning of future similar projects.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

PREFACE

From 1977 to 1979, the U.S. Environmental Protection Agency's, Municipal Environmental Research Laboratory contracted with Culp/Wesner/Culp, Clean Water Consultants (CWC) for the preparation of a series of reports estimating the costs for municipal water treatment. During the course of this work, the costs of granular activated carbon (GAC) adsorption and reactivation in municipal water treatment as they relate to the removal of organics from drinking water became a subject of great national interest. Because of this, in 1978, the original project was expanded to include a special study of the unit process costs of GAC adsorption and reactivation in potable water treatment. This special study was directed at visiting as many existing GAC installations as possible to gather and publish data on actual operating experiences, particularly on the costs of building, operating, and maintaining GAC plants. This report presents the findings of this special study of GAC installations and the compilation of the information available on the use of GAC in water treatment.

ABSTRACT

This report compiles and summarizes design criteria, performance data, and cost information from twenty-two operating granular activated carbon (GAC) installations. These plants produce municipal water for drinking, treat municipal and industrial wastewaters, and process food and beverage products. It provides guidance in estimating the cost of GAC treatment for public water supplies. The manual is intended for use in connection with a previous series of EPA reports on "Estimating Water Treatment Costs" to obtain project-specific cost estimates. This manual is not a design manual. Rather, it describes how to obtain design criteria for water systems.

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ABBREVIATIONS

avg	average
AWT	advanced wastewater treatment
BLS	Bureau of Labor Statistics
BOD	Biological Oxygen Demand
BSP	Bartlett-Snow-Pacific Inc.
Btu	British thermal unit
CCI	Construction Cost Index
cm	centimeter(s)
COD	Chemical Oxygen Demand
cu	cubic
d	day(s)
dia	diameter
EBCT	empty bed contact time
ENR	Engineering News Record
GAC	granular activated carbon
gal	gallon(s)
gpm	gallon(s) per minute
hr	hour(s)
I.D.	Inside diameter
in.	inch(es)
JTU	Jackson turbidity units
kg	kilogram(s)
kwh	kilowatt hour(s)
l	liter(s)
lb	pound(s)
m	meter(s)
max	Maximum
MBAS	Methylene blue active substances
mgd	million gallon(s) per day
mg/L	milligram(s) per liter
mhr	manhour(s)
mil	million
min	minute(s) or minimum
O&M	operation and maintenance
PAC	powdered activated carbon
psi	pound(s) per square inch
scf	standard cubic feet
sq	square
SS	suspended solids
SWD	side wall depth
THM	trihalomethane
TOC	Total Organic Carbon
TON	threshold odor number

Abbreviations (Continued)

TN	total nitrogen
TP	total phosphorus
TTSA	Tahoe-Truckee Sanitation Agency
w/	with
yr	year
304SS	stainless steel
316SS	stainless steel

CONVERSION TO METRIC

English units have been used throughout this report. For the readers convenience the following table can be used to convert to metric units.

English Units	Multiplier	Metric Units
in.	2.54	cm
ft	0.305	m
sq ft or ft^2	0.093	sq m or m^2
acre	0.405	hectares
cu ft of ft^3	0.028	cu m or m^3
gal	3.79	L
gpm	227	L/hr
mgd	3785	cu m/d or m^3/d
lb	0.454	kg
°F	5/9(°F-32)	°C
¢/1000 gal	0.26	¢/cu m

ACKNOWLEDGEMENT

The authors hereby acknowledge the valuable assistance of Stephen W. Work, Denver Water Department, Robert L. Chapman, CH2M/Hill Engineers, Dr. Robert M. Clark, U.S. EPA, and Marion Curry, editor, in the review and completion of this report.

SECTION 1

INTRODUCTION

On January 9, 1978, the U.S. Environmental Protection Agency (EPA) proposed the use of Granular Activated Carbon (GAC) as a means of treating drinking water. Since that time much has been written both for and against using GAC in this manner. Serious challenges and many questions have been raised regarding EPA's cost estimates for GAC use. To respond to some of these questions, EPA's Drinking Water Research Division initiated a carefully designed study to establish water supply unit process cost curves on a consistent and understandable basis.

A study performed by Culp/Wesner/Culp under EPA Contract No. 68-03-2516, focused on processes capable of removing those contaminants included in the National Interim Primary Drinking Water Regulations and developed construction and operation and maintenance cost curves for these processes. Its final report contains cost curves for 99 different unit processes. These cost curves were divided into two categories, large water treatment systems applicable to flows between 1 and 200 mgd and small water treatment systems applicable to flows between 2,500 gpd and 1 mgd. A computer program for retrieving, updating, and combining the cost data was also developed. During the course of this work, the costs of granular activated carbon (GAC) adsorption and reactivation in municipal water treatment as they relate to the removal of organics from drinking water became a subject of great national interest. Because of this, in 1978, the original project was expanded to include a special study of the unit process costs of GAC adsorption and reactivation in potable water treatment. The special study was directed at visiting as many existing GAC installations as possible to gather and publish data on actual operating experiences, particularly on the costs of building, operating, and maintaining GAC plants. This report presents the findings of this special study of GAC installations and the compilation of the information available on the use of GAC in water treatment.

This manual compiles and summarizes carbon treatment design criteria, performance, and cost data from 22 operating municipal and industrial GAC installations for treatment of water and wastewater and for processing food and beverage products. It provides guidance and an example of how this information can be used to estimate the cost for granular carbon treatment of water supplies. The manual should be used in conjunction with the series of reports on "Estimating Water Treatment Costs" to obtain project-specific cost estimates. This manual is not a design manual and it does not provide design criteria such as required contact time, probable regeneration frequency, carbon regeneration system criteria, or carbon transfer guidelines. Rather, the approach to determining such design data is presented.

Powdered activated carbon (PAC) has been used for more than 50 years in the removal of taste and odor from public water supplies, without harmful effects, but the use of granular activated carbon (GAC) in the treatment of municipal water in the U.S. is limited to a few facilities. In most cases, GAC is used to remove taste and odor from drinking water. Its use may become more common in light of new information on the occurrence of trace organics in water, the recent regulations limiting the concentration of trihalomethanes in public water supplies, and the possibility of requirements for carbon treatment. European water works have had considerable experience over a long period of time with GAC installations.

Unlike the limited use of GAC in municipal water treatment, GAC has been used in industrial and municipal wastewater treatment and in various industrial process applications. Although the specific uses of GAC are somewhat different with these applications than with water treatment, much of the information on design and operations will prove useful to water purveyors. In general, the application of GAC adsorption to drinking water is simpler than to wastewater.

A series of case studies has been prepared as a result of site visits and literature searches. Twenty-two GAC installations were visited; 18 of these were industrial process or municipal wastewater facilities, whereas 4 were municipal water treatment plants. Case histories presenting design, operating, performance, and cost information are presented in the Appendix; the pertinent information has been summarized (Table 1). Single page fact sheets for each of these case histories follow Table 1.

A principal function of the site visits was to collect construction and operation and maintenance (O&M) cost information on GAC installations. Plant records were used to obtain available construction costs, the dates for these costs, and the most recent O&M costs. The basic data are presented in the individual case study reports, but no attempt was made to update construction or O&M costs to present day prices or to convert the costs to water treatment plants. This report does, however refer to procedures whereby data from existing GAC projects can be adjusted or modified (based on the results of pilot plant test results of the water to be treated) so as to be useful to experienced professionals in the field in making preliminary estimates of costs for future potable water projects involving GAC adsorption and reactivation or replacement.

TABLE 1. SUMMARY OF GAC SYSTEM CHARACTERISTICS

Case No.	Owner	Type of facility	Flow, mgd	Pretreatment	Carbon contactors Contact time, min	Carbon contactors Hydraulic loading, gpm/ft^2
1	South Tahoe	Municipal wastewater	7.5(max)	Extensive	17	6.5
2	Tahoe-Truckee	Municipal wastewater	4.83(max)	Extensive	20	
3	Upper Occoquan	Municipal wastewater	15.0(avg)	Extensive	22	8.4
4	American Cyanamid	Chemprocess	20.0(avg)	Extensive	30	8.0
5	Vallejo	Municipal wastewater	13.0(avg)	Moderate	25	6.0
6	Orange Co.	Secondary effluent	15.0(max)	Extensive	34	5.8
7	Niagara Falls	Municipal w/ significant industrial	48.0(avg)	Moderate	40	1.67
8	Fitchburg¥	Municipal w/ significant industrial	15.0(avg)	Moderate	15	8.00
9	Arco Petroleum	Process wastes w/significant industrial	4.32(max)	Minimal	56	1.74
10	Rhone-Poulenic	Herbicide production wastes	0.15(max)	None	87	2.00
11	Reichhold Chemicals	Chemical production wastes	1.0(max)	Moderate	100	1.55
12	Stepan Chemicals	Surfactant production wastes	0.015(max)	None	500	-
13	Republic Steel§	Coke process wastes	0.95(max)	Minimal	116/58	2.3/4.6
14	LeRoy	Municipal wastewater	1.0(max)	Extensive	12	-
15	Manchester	Water supply	40.0(max)	Moderate	14	-
16	Passaic Valley††	Water supply	2.2(max)	Extensive	8	-
17	Colorado Springs	Secondary effluent	2.0(max)	Extensive	17	4.5
18	Hercules	Chemical production wastes	3.25(max)	Moderate	48	6.6
19	Industrial sugar	Decoloring sugar	-	Minimal	1080	-
20	Hopewell	Water supply	3.0(mg)	Moderate	-	2.0
21	Davenport	Water supply	30.0(max)	Moderate	7.5	2.0
22	Spreckles Sugar	Sugar thick juice	-	None	20	-

*Not available

¥Facility under construction

§Two separate treatment trains

†Fluidized bed

††GAC test facility

§§kw/lb carbon

TABLE 1. (Continued)

Furnace				Carbon Dose		Costs		
						Capital		
Rated capacity, lb carbon/day	Carbon loss, %	Fuel type	Use, Btu/lb carbon	lb/mil gal	lb organic/ lb carbon	Capital, $1000 (year)	$/lb day capacity	O&M, $/mil gal (year)
6,000	8	Gas	2,900	207	0.38	849(1969)	141.50	36.07(1979)
3,840	5	Propane	3,840		0.33	1,569(1976)	408.59	N/A*
12,000	10	LPG	2,750	250	0.33	3,880(N/A)	323.33	50.00(1979)
122,000	9	-	-	-	-	N/A	-	N/A
29,000	7.5	-	-	1,410	0.50	4,359(1974)	150.31	N/A
12,000	6	Natural gas	5,600	-	1.70	3,307(1972)	275.58	90.49(1979)
-	-	-	-	-	-	N/A	-	N/A
-	5	-	-	-	-	N/A	-	N/A
8,500	5	Natural gas	-	1,000	0.26	1,000(1971)	117.65	490.00(1973)
8,500	8.8	Natural gas	6,500	43,000	0.38	300(1969)	35.29	319.00(1973)
32,500	5	Natural gas	6,200	79,000	0.26	N/A	-	N/A
6,480	6	LPG	6,000	500,000	-	225(1973)	34.72	25,000(1978)
68,000	8	Natural gas	-	35,000	-	N/A	-	N/A
12,000	-	Fuel oil	-	-	-	2,500(1975)	208.33	N/A
12,000†	10	Fuel oil	-	-	-	N/A	-	N/A
2,400	10	Electricity	0.7§§	-	-	N/A	-	N/A
1,800	7.5	-	-	160	0.50	N/A	-	89.59
33,600	5	Natural gas	7,000	9,500	0.44	1,622(1973)	48.27	1,470.00
12,000	2.5	Natural gas	-	-	-	N/A	-	N/A
None	-	-	-	-	-	N/A	-	30.00(1980)
None	-	-	-	-	-	N/A	-	20.00(1980)
15,000	4.8	Natural gas	1,785	-	-	238(1958)	15.87	N/A

MUNICIPAL WASTEWATER TREATMENT
FACT SHEET
CASE HISTORY NO. 1
SOUTH TAHOE (CALIFORNIA) PUBLIC UTILITY DISTRICT

Type of Wastewater: Municipal

Size of Treatment Facility: 7.5 mgd (maximum)

Date of GAC Startup: 1966

Pretreatment: Primary, activated sludge, lime clarification, ammonia stripping, recarbonation, filtration

Purpose of GAC: Dissolved organics removal, effluent discharged to recreational impoundment

GAC Design Features:

- Type of contactors - upflow, packed bed, countercurrent
- Number, size, and bed depth - eight; 12-ft dia x 12-ft straight sidewall; 14.5 ft
- Minimum contact time - 17 min
- Hydraulic (surface) loading - 6.5 gpm/ft^2
- Carbon size - 8 x 30 mesh

GAC Reactivation Furnace:

- Type and size - six hearth; 54-in. dia
- Rated capacity - 6,000 lb carbon/day
- Regeneration temperature - 1650° to 1750°F
- Type of fuel - gas with propane standby
- Fuel demand - 2,900 Btu/lb carbon
- Carbon loss - 8%

System Performance:

	COD	MBAS	Color
Concentration in, mg/L	20.3	0.6	11 (color units)
Concentration out, mg/L	10.0	0.1	5-6 (color units)
Removal efficiency, %	51	77	50

- Carbon dose rate - 0.38 lb COD removed/lb carbon
- Carbon exhaustion - 207 lb carbon/mil gal treated

Capital Costs (1969):

GAC units with carbon - $656,000
Reactivation system - 193,000
$849,000

O&M Costs (1970):

Adsorption - $10.74/mil gal
Reactivation - 25.33/mil gal
$36.07/mil gal

MUNICIPAL WASTEWATER TREATMENT
FACT SHEET
CASE HISTORY NO. 2
TAHOE-TRUCKEE (CALIFORNIA) SANITATION DISTRICT

Type of Wastewater: Municipal
Size of Treatment Facility: 4.83 mgd (maximum)
Date of GAC Startup: 1979
Pretreatment: Primary, pure oxygen activated sludge, lime clarification, two-stage recarbonation, mixed media filtration
Purpose of GAC: Organics removal, effluent discharged to Truckee River
GAC Design Features:
  Type of contactors - upflow, packed bed, countercurrent
  Number, size, and bed depth - six; 12-ft dia x 20-ft straight sidewall; 20 ft
  Minimum contact time - 20 min
  Carbon size - 8 x 30 mesh
GAC Reactivation Furnace:
  Type and size - six hearth; 81-in. dia
  Rated capacity - 3,840 lb carbon/day plus 1,980 lb adsorbate/day
  Hearth loading - 45 lb/day/ft^2
  Type of fuel - propane with fuel oil standby
  Fuel demand - 3,780 Btu/lb carbon plus adsorbate
  Carbon loss - 5%
System Performance:
  Carbon dose rate - 0.33 lb COD removed/lb carbon
Capital Costs (1976):
  GAC units with carbon - $ 619,000
  Reactivation system - 950,000
  $1,569,000

O&M Costs: Not available

MUNICIPAL WASTEWATER TREATMENT
FACT SHEET
CASE HISTORY NO. 3
UPPER OCCOQUAN (VIRGINIA) SEWAGE AUTHORITY

- Type of Wastewater: Municipal
- Size of Treatment Facility: 15 mgd (average)
- Date of GAC Startup: 1978
- Pretreatment: Primary, activated sludge, lime clarification, two-stage recarbonation, mixed media filtration
- Purpose of GAC: Soluble organics removal, effluent disposal to domestic water supply reservoir
- GAC Design Features:
  - Type of contactors - upflow, countercurrent
  - Number, size, and bed depth - sixteen; 12-ft dia x 24-ft straight sidewall; 24.3 ft
  - Minimum contact time - 22 min
  - Hydraulic (surface) loading - 8.40 gpm/ft^2
  - Carbon size - 8 x 30 mesh
- GAC Reactivation Furnace:
  - Type and size - two at seven-hearth; 129-in. OD
  - Rated capacity - 12,000 lb/day
  - Hearth loading - 45 lb/day/ft^2
  - Type of fuel - liquid propane gas
  - Fuel demand - 2,750 lb/day
  - Carbon loss - 10%
- System Performance: Operation based on column effluent upper and lower COD of 10 mg/L
  - Carbon dose rate - 0.18 to 0.33 lb COD/lb carbon
  - Carbon exhaustion - 250 lb carbon/mil gal treated
- Capital Costs (N/A*):
  - GAC units with carbon - $2,250,000
  - Reactivation system - 1,630,000
  - $3,880,000
- O&M Costs (1979): $50.00/mil gal

---

*Date not available

INDUSTRIAL WASTEWATER TREATMENT
FACT SHEET
CASE HISTORY NO. 4
AMERICAN CYANAMID CO., ORGANIC CHEMICALS DIVISION
BOUND BROOK, NEW JERSEY

Type of Wastewater: Chemical wastes, sanitary sewage, cooling water, stormwater runoff
Size of Treatment Facility: 20 mgd (average)
Date of GAC Startup: 1977
Pretreatment: Primary with lime neutralization, activated sludge, mixed media filtration
Purpose of GAC: Color, odor, toxicity and suspended solids (refractory organics) removal; effluent disposal comprises up to 25 percent Raritan River flow
GAC Design Features:
  Type of contactors - expanded upflow, countercurrent
  Number, size, and bed depth - ten; 16-ft dia x 40-ft straight sidewall; 30 ft
  Minimum contact time - 30 min
  Hydraulic (surface) loading - 8.0 gpm/ft^2
  Carbon size - 8 x 30 mesh
GAC Reactivation Furnace:
  Type and size - eight-hearth; 309-in. dia
  Rated capacity - 122,000 to 152,000 lb/day
  Regeneration temperature - 1750°F
  Carbon loss - 9%
System Performance: TOC removal in pilot studies averaged 68%
Capital Costs: Not available
O&M Costs: Not available

MUNICIPAL WASTEWATER TREATMENT
FACT SHEET
CASE HISTORY NO. 5
VALLEJO (CALIFORNIA) SANITATION AND FLOOD CONTROL DISTRICT

Type of Wastewater: Municipal
Size of Treatment Facility: 13 mgd (average)
Date of GAC Startup: 1979
Pretreatment: Lime sedimentation, single-stage recarbonation
Purpose of GAC: Organic and suspended solids removal; effluent discharge to Carquinez Straight

GAC Design Features:
- Number, size, and bed depth - six; 18-ft square; 16 ft
- Minimum contact time - 25 min
- Hydraulic (surface) loading - 6 gpm/ft^2
- Carbon size - 12 x 40 mesh

GAC Reactivation Furnace:
- Type and size - six-hearth; 12 ft ID
- Rated capacity - 29,000 lb/day
- Hearth loading - 3 lb/hr ft^2
- Regeneration temperature - 1500°F
- Carbon loss - 7.5%

System Performance:

	COD	MBAS	SS
Concentration in, mg/L	175	104	66
Concentration out, mg/L	90	45	22
Removal efficiency, %	49	57	67

- Carbon dose rate - 0.5 lb COD removed/lb carbon
- Carbon exhaustion - 1,410 lb carbon/mil gal treated

Capital Costs (1974):

GAC units with carbon -	$2,929,000
	1,430,000
	$4,359,000

O&M Costs: Not available

WASTEWATER RECLAMATION
FACT SHEET
CASE HISTORY NO. 6
ORANGE COUNTY (CALIFORNIA) WATER DISTRICT

Type of Wastewater: Secondary effluent
Size of Facility: 15 mgd
Date of GAC Startup: 1976
Pretreatment: Lime clarification, air stripping, recarbonation, chlorination, filtration
Purpose of GAC: Organics removal, effluent injection to prevent sea water intrusion
GAC Design Features:
  Type of contactors - downflow
  Number and size - seventeen; 12-ft dia x 24-ft straight sidewall
  Minimum contact time - 34 min
  Hydraulic (surface) loading - 5.8 gpm/ft^2
  Carbon size - 8 x 30 mesh
GAC Reactivation Furnace:
  Type - six-hearth
  Rated capacity - 12,000 lb/day
  Regeneration temperature - 1650°F
  Type of fuel - natural gas
  Fuel demand - 5,600 Btu/lb carbon
  Carbon loss- 6%
System Performance:

	COD	TOC
Concentration in, mg/L	42.0	14.4
Concentration out, mg/L	16.6	7.0
Removal efficiency, %	60	51

  Carbon dose rate - 1.7 lb COD removed/lb carbon
Capital Costs (1972): $3,307,000
O & M Costs (1979):

Adsorption -	$29.80/mil gal
Reactivation -	60.69/mil gal
	$90.49/mil gal

MUNICIPAL WASTEWATER TREATMENT
FACT SHEET
CASE HISTORY NO. 7
CITY OF NIAGARA FALLS, NEW YORK

Type of Wastewater: Municipal with significant industrial contribution
Size of Treatment Facility: 48 mgd (average)
Date of GAC Startup: 1977
Pretreatment: Chemical clarification, acid addition
Purpose of GAC: Dissolved organics removal, effluent discharge to Niagara River
GAC Design Features:
  Type of contactors - open-top, downflow
  Number, size, and bed depth - twenty-eight; 17.3-ft x 42-ft rectangular; 8.75 ft
  Minimum contact time - 40 min
  Hydraulic (surface) loading - 1.67 gpm/ft^2
GAC Reactivation Furnace:
  Type and size - six-hearth; 14.25-ft dia
System Performance: Not available
Capital Costs: Not available
O&M Costs: Not available

MUNICIPAL WASTEWATER TREATMENT
FACT SHEET
CASE HISTORY NO. 8
CITY OF FITCHBURG, MASSACHUSETTS

Type of Wastewater: Municipal and industrial (significant paper processing wastes)

Size of Treatment Facility: 15 mgd (average)

Date of GAC Startup: Under construction

Pretreatment: Primary, lime clarification, alum addition as required

Purpose of GAC Removal: BOD, COD, color removal, portion of effluent to be used by paper processer

GAC Design Features:

- Type of contactors - downflow, series
- Number, size and bed depth - twelve; 20-ft dia, 30-ft height; 15.5 ft
- Minimum contact time - 15 min
- Hydraulic (surface) loading - 8 gpm/ft^2

GAC Regeneration Furnace:

- Type - multiple hearth
- Hearth loading - 4.17 lb/hr/ft^2
- Carbon loss- 5%

System Performance (pilot study):

	COD	BOD
Concentration in, mg/L	53.4	13.2
Concentration out, mg/L	6.8	1.7
Removal efficiency, %	87	87

Capital Costs: Not available

O&M Costs: Not available

INDUSTRIAL WASTEWATER TREATMENT
FACT SHEET
CASE HISTORY NO. 9
ARCO PETROLEUM PRODUCTS COMPANY, WATSON REFINERY
CARSON, CALIFORNIA

Type of Wastewater: Process wastes and storm water runoff (stored prior to treatment)
Size of Treatment Facility: 3,000 gpm (maximum)
Date of GAC Startup: 1971
Pretreatment: Reservoir storage
Purpose of GAC: Soluble COD and phenols removal, effluent discharged to Dominquez Channel
GAC Design Features:
  Type of contactors - downflow, gravity, parallel
  Number, size, and bed depth - twelve; 12-ft x 12-ft x 26-ft deep; 13 ft
  Minimum contact time - 56 min
  Hydraulic (surface) loading - 1.74 gpm/ft^2
  Carbon size - 8 x 30 mesh
GAC Reactivation Furnace:
  Type and size - six hearth; 56-in. ID
  Rated capacity - 8,500 lb/day carbon
  Regeneration temperature - 1600° to 1750°F
  Type of fuel - natural gas
  Fuel demand - 3,000 SCFH
  Carbon loss - 5%
System Performance:

	COD	Oil
Concentration in, mg/L	233	28
Concentration out, mg/L	48	12
Removal efficiency, %	79	57

  Carbon dose rate - 0.26 lb COD removed/lb carbon
  Carbon exhaustion - 1,000 lb/carbon/mil gal treated
Capital Costs (1971): Approximately $1 million
O&M Costs (1971-73): $490.00/mil gal

INDUSTRIAL WASTEWATER TREATMENT
FACT SHEET
CASE HISTORY NO. 10
RHONE-POULENIC INC.
PORTLAND, OREGON

Type of Wastewater: Herbicide production wastewater
Size of Treatment Facility: 0.15 mgd (maximum)
Date of GAC Startup: 1969
Pretreatment: None
Purpose of GAC: Phenol removal, effluent discharged to City sewer system
GAC Design Features:
  Type of contactors - upflow series, no backwash
  Number, size, and bed depth - two; 8-ft ID x 35-ft height; 12 ft
  Minimum contact time - 87 min
  Hydraulic (surface) loading - 2.0 gpm/ft^2
  Carbon size - 12 x 40 mesh
GAC Reactivation Furnace (reactivation off-site since 1977):
  Type and size - six-hearth; 54-in. ID
  Rated capacity - 8,500 lb/day
  Regeneration temperature - 1600° to 1800°F
  Type of fuel - natural gas
  Fuel demand - 6,500 Btu/lb carbon
  Carbon loss - 8.8%
System Performance:

	Ortho-cresol	Total Phenol
Concentration in, mg/L	16.5	52.9
Concentration out,* mg/L	0.62	0.69
Removal efficiency, %	96	99

  Carbon dose rate - 0.38 lb organics removed/lb carbon
  Carbon exhaustion - 43,000 lb carbon/mil gal treated
Capital Costs (1969): $300,000
O&M Costs (1973): $319.00/mil gal

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*Two-stage series

INDUSTRIAL WASTEWATER TREATMENT
FACT SHEET
CASE HISTORY NO. 11
REICHHOLD CHEMICALS INC.
TUSCALOOSA, ALABAMA

Type of Wastewater: Chemical production wastewater
Size of Treatment Facility: 10 mgd (maximum)
Date of GAC Startup: 1973
Pretreatment: Neutralization, clarification with polymer
Purpose of GAC: Dissolved organics (including phenol) removal, effluent discharged to Black Warrior River
GAC Design Features:
  Type contactors - upflow, countercurrent, parallel
  Number, size, and bed depth - two; 12-ft dia x 40-ft depth
  Minimum contact time - 100 min
  Hydraulic (surface) loading - 1.55 gpm/ft^2
  Carbon size - 8 x 30 mesh
GAC Reactivation Furnace:
  Type and size - six-hearth; 13.5-ft ID
  Rated capacity - 32,500 lb/day
  Regeneration temperature - 1700°F
  Type of fuel - natural gas, liquid propane gas standby
  Fuel demand - 6,200 Btu/lb carbon
  Carbon loss - 5%
System Performance:

	COD	BOD	Phenol
Quantity in, lb/day	9750	3640	867
Quantity out, lb/day	1868	1078	1.45
Removal efficienty, %	81	70	99+

  Carbon dose rate - 0.26 lb COD removed/lb carbon
  Carbon exhaustion - 79,000 lb carbon/mil gal treated
Capital Cost (N/A*): $1.3 million (complete plant)
O&M Cost (1976): $793.00/mil gal (all treatment)

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*Date not available.

INDUSTRIAL WASTEWATER TREATMENT
FACT SHEET
CASE HISTORY NO. 12
STEPAN CHEMICAL COMPANY
BORDENTOWN, NEW JERSEY

Type of Wastewater: Surfactant process wastewater
Size of Treatment Facility: 15,000 gpd
Date of GAC Startup: 1972
Pretreatment: None
Purpose of GAC: Organics removal, effluent discharged to Delaware River
GAC Design Features:
  Type of contactors - downflow, pressure, series
  Number, size and bed depth - three; 6-ft dia x 10-ft height; 7.5 ft
  Minimum contact time - 500 min
  Carbon size - 8 x 30 mesh
GAC Reactivation Furnace:
  Type and size - six-hearth; 54-in. ID
  Rated capacity - 6,480 lb/day
  Regeneration temperature - 1600° to 1800°F
  Type of fuel - liquid propane gas
  Fuel demand - 6,000 Btu/lb carbon
  Carbon loss - 6%
System Performance:

	COD	BOD	TOC	MBAS
Effluent concentration, mg/L	117	16	19	0.12

  Carbon exhaustion - 500,000 lb carbon/mil gal treated
Capital Costs (1973): $225,000
O&M Costs (1978): $25,000/mil gal

INDUSTRIAL WASTEWATER TREATMENT
FACT SHEET
CASE HISTORY NO. 13
REPUBLIC STEEL CORPORATION
CLEVELAND, OHIO

Type of Wastewater: Coke process wastewater
Size of Treatment Facility: 220 gpm (System A), 440 gpm (System B)
Date of GAC Startup: 1977
Pretreatment: Chemical addition, dissolved gas flotation, media filtration
Purpose of GAC: Phenol removal, effluent discharge to surface water
GAC Design Features:
  Type contactors - two separate systems; downflow, series, no backwash
  Number, size, and bed depth (each system) - 2; 11-ft dia x 24.5-ft height; 18 ft
  Minimum contact time - 116 min (A), 58 min (B)
  Hydraulic (surface) loading - 2.3 gpm/ft^2 (A), 4.6 gpm/ft^2 (B)
GAC Reactivation Furnace:
  Type and size - eight-hearth; 16-ft OD
  Rated capacity - 68,000 lb/day
  Regeneration temperature - 1600° to 1800°F
  Type of fuel - natural gas, coke oven gas standby
  Carbon loss - 5 to 8%

System Performance (A)	Phenol
Cencentration in, mg/L	30.0
Concentration out, mg/L	0.025
Removal efficiency, %	99+

  Carbon exhaustion - 35,000 lb/mil gal (A), 25,000 lb/mil gal (B)
Capital Costs (N/A*): $10 million (complete system)
O&M Costs (N/A*): $8,000/day (complete treatment)

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*Date not available.

MUNICIPAL WASTEWATER TREATMENT
FACT SHEET
CASE HISTORY NO. 14
VILLAGE OF LE ROY, NEW YORK

Type of Wastewater: Municipal
Size of Treatment Facility: 1 mgd (maximum)
Date of GAC Startup: 1978
Pretreatment: Clariflocculation, rapid sand filtration
Purpose of GAC: Residual organics removal, effluent discharge to Oatka Creek
GAC Design Features:
  Number and size - four; 11-ft dia
  Minimum Contact Time - 12 min
Gas Reactivation Furnace:
  Type and size - five-hearth; 9.25-ft OD
  Rated Capacity - 12,000 lb/day
  Type of fuel - No. 2 fuel oil
  Fuel demand - 30,000 gal/yr
  Carbon loss - 8.5%
System Performance: Not available
Capital Costs (1975): $2,500,000
O&M Costs: Not available

MUNICIPAL WATER PURIFICATION
FACT SHEET
CASE HISTORY NO. 15
CITY OF MANCHESTER, NEW HAMPSHIRE

Type of Water: Raw water
Size of Treatment Facilities: 40 mgd
Date of GAC Startup: 1974
Pretreatment: Chemical clarification, sand filtration
Purpose of GAC: Taste, odor and volatile organics removal from potable water supply
GAC Design Features:
  Type of contactors - series with sand filtration, downflow
  Number and bed depth - four; 4-ft
  Minimum contact time - 14 to 22 min
  Hydraulic (surface) loading - 4.0 gpm/ft^2
  Carbon size - 8 x 30 mesh
GAC Reactivation Furnace:
  Type - fluidized bed
  Rated capacity - 12,000 lb/day
  Type of fuel - fuel oil
  Fuel demand - 240 gal/day
  Carbon loss - 10%
System Performance (complete processing):

	Color (color units)	TOC
Concentration in, mg/L	15	4.0
Concentration out, mg/L	1	1.8
Removal efficiency, %	93	55

Capital Costs (1979): $882,406 (reactivation only)
O&M Costs: Not available

MUNICIPAL WATER PURIFICATION
FACT SHEET
CASE HISTORY NO. 16
PASSAIC VALLEY (NEW JERSEY) WATER COMMISSION

Type of Water: Raw water
Size of Treatment Facility: 2.2 mgd GAC Test Facility
Date of GAC Startup: 1978
Pretreatment: Prechlorination, alum clarification, dual-media filtration
Purpose of GAC: Experimental testing of GAC regeneration
GAC Design Features:
  Minimum contact time - 8 min, pressure filters, downflow
GAC Reactivation Furnace:
  Type and size - infrared tunnel; 4 ft x 20 ft
  Rated capacity - 2,400 lb/day
  Regeneration temperature - 1600°F
  Type of fuel - electric power (100 kw)
  Fuel demand - 0.7 kw/lb carbon
  Carbon loss - 8 to 10%
System Performance: TOC removal 20 to 40%
Capital Costs: Not available
O&M Costs: Not available

MUNICIPAL WASTEWATER TREATMENT FACT SHEET
CASE HISTORY NO. 17
COLORADO SPRINGS, COLORADO

Type of Wastewater: Secondary effluent (overloaded bio-filters)
Size of Treatment Facility: 2 mgd
Date of GAC Startup: 1970
Pretreatment: Lime clarification, dual media filtration
Purpose of GAC: Organics removal, effluent recycled for industrial use
GAC Design Features:
  Type of contactors - downflow, series
  Number, size, and bed depth - three; 20-ft dia x 14-ft straight sidewall; 8 ft
  Minimum contact time - 17 min
  Hydraulic (surface) loading - 4.5 gpm/ft^2
  Carbon size - 8 x 30 mesh
GAC Reactivation Furnace:
  Type and size - one, six-hearth; 3-ft dia
  Rated capacity - 1,800 lb/day
  Regeneration temperature - 1650°F
  Carbon loss - 7.5%
System Performance:

	COD	BOD	TOC	MBAS	COLOR*
Concentration in, mg/L	57	27	24	1.7	17.0
Concentration out, mg/L	31	13	10	0.4	7.4
Removal efficiency, %	46	52	58	76	56

  Carbon dose rate - 0.50 lb COD removed/lb carbon
  Carbon exhaustion - 160 lb/mil gal treated
Capital Costs: Not available
O&M Costs (1972): $89.59/mil gal

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*Color units.

INDUSTRIAL WASTEWATER TREATMENT
FACT SHEET
CASE HISTORY NO. 18
HERCULES, INC.
HATTIESBURG, MISSISSIPPI

Type of Wastewater: Industrial chemical process wastewater
Size of Treatment Facilities: 3.25 mgd
Date of GAC Startup: 1973
Pretreatment: Impoundment, dissolved air flotation, mixed media filtration
Purpose of GAC: Phenol and TOC removal, effluent discharged to Bowie River
GAC Design Features:
  Type of contactors - upflow, countercurrent
  Number and size - three; 12-ft dia x 40-ft height
  Minimum contact time - 48 min
  Hydraulic (surface) loading - 6.6 gpm/ft^2
  Carbon size - 12 x 40 mesh
GAC Reactivation Furnace (replaced with fluidized bed furnace in 1977):
  Type and size - five-hearth; 12-ft OD
  Rated capacity - 33,600 lb/day
  Regeneration temperature - 1600° to 1800°F
  Type of fuel - natural gas, fuel oil standby
  Fuel demand - 6,000-7,000 Btu/lb carbon
  Carbon loss - 5%
System Performance:

	TOC	Phenolics
Concentration in, mg/L	292	-
Concentration out, mg/L	168	0.13
Removal efficiency, %	43	-

  Carbon dose rate - 0.1 to 0.44 lb TOC removed/lb carbon
  Carbon exhaustion - 9,500 lb carbon/mil gal treated
Capital Costs (1973): $1,622,000
O&M Costs (1979): $1,470/mil gal

FOOD PROCESSING
FACT SHEET
CASE HISTORY NO. 19
INDUSTRIAL SUGAR, INC.
ST. LOUIS, MISSOURI

Type of Liquid: Liquid sugar
Size of Treatment Facility: Not applicable
Date of GAC Startup: 1958
Processing: Filtration for particulate impurity removal
Purpose of GAC: Decoloring liquid sugar
GAC Design Features:
  Type of contactors - downflow, series
  Number, size, and bed depth - six; 6-ft dia x 9-ft height; four; 10-ft dia x 9-ft height; 9 ft
  Minimum contact time - 18 hr total
  Carbon size - 12 x 40 mesh
Gas Reactivation Furnace:
  Type and size - six-hearth; 6-ft OD
  Rated capacity - 12,000 lb/day
  Regeneration temperature - 1600°F
  Type of fuel - natural gas
  Carbon loss - 2.5%
System Performance:
  Carbon exhaustion - 2 lb carbon/100 lb raw sugar
Capital Costs (1965): $125,000 reactivation system only
O&M Costs: Not available

MUNICIPAL WATER PURIFICATION
FACT SHEET
CASE HISTORY NO. 20
AMERICAN WATER WORKS SERVICE COMPANY
HOPEWELL, VIRGINIA

Type of Water: Raw water

Size of Treatment Facility: 3 mgd

Date of GAC Startup: 1960

Pretreatment: Chemical coagulation, settling, filtration through spent carbon

Purpose of GAC: Municipal water purification - taste and odor removal; spent carbon used for filtration and dechlorination

GAC Design Features:

Bed depth - 24 in.

Hydraulic (surface) loading - 2 gpm/ft^2

GAC Regeneration Furnace: None

System Performance:

	Color*	Mn	Pb	Turbidity†	Chlorine
Concentration in, mg/L	4-14	0.15	0.37	1.4	2.8
Concentration out, mg/L	0-2	0.017	0.025	0.15	0.25
Removal Efficiency, %	86-100	89	89	89	91

Capital Costs: Not available

O&M Cost (1980): $30.00/mil gal

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*Color Units

†JTU

MUNICIPAL WATER PURIFICATION
FACT SHEET
CASE HISTORY NO. 21
AMERICAN WATER WORKS SERVICE COMPANY
DAVENPORT, IOWA

Type of Water: Raw water
Size of Treatment Facility: 18 to 20 mgd (avg), 30 mgd (max)
Date of GAC Startup: 1973 (conversion of gravity sand filters to GAC)
Pretreatment: Prechlorination, coagulation, sedimentation, filtration
Purpose of GAC: Municipal water purification - taste, odor, turbidity and trihalomethane (THM) removal
GAC Design Features:
  Type of contactors - gravity (converted sand filters)
  Number and bed depth - twenty; 24 in.
  Minimum contact time - 7.5 min
  Hydraulic (surface) loading - 2 gpm/ft^2
GAC Reactivation Furnace: None
System Performance:

	Turbidity*	TOC	THM†
Concentration in, mg/L	3	5.3	97
Concentration out, mg/L	0.32	4.2	69
Removal efficiency, %	89	21	29

Capital Costs: Not available
O&M Costs (1980): $20.00/mil gal

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*NTU
†mg/L

FOOD PROCESSING
CASE HISTORY NO. 22
SPRECKLES SUGAR
WOODLAND, CALIFORNIA

Type of Liquid: Sugar juice
Size of Treatment Facility: Not applicable
Date of GAC: Removal of color and impurities from beet sugar thick juice
GAC Design Features:
- Type of contactors - upflow expanded, continuous adsorption process (CAP)
- Number, size, and bed depth - three; 9.5-ft dia x 47.6-ft height; 13 to 14 ft
- Minimum contact time - 20 min
- Carbon size - 12 x 40 mesh

GAC Reactivation Furnace:
- Type and size - six-hearth; 8.33-ft dia
- Rated capacity - 15,000 lb/day
- Regeneration temperature - 1600° to 1720°F
- Type of fuel - natural gas
- Fuel demand - 1,785 Btu/lb carbon
- Carbon loss - 4.8%

System Performance: Not available
Capital Costs (1958):
- GAC units, carbon, rotary kiln furnace - $238,000

O&M Costs: Not available

SECTION 2

HISTORICAL USE OF ACTIVATED CARBON IN WATER PURIFICATION

POWDERED CARBON

Powdered activated carbon (PAC) has been used successfully for more than 50 years to remove taste and odor from public drinking water supplies. Except for partical size, this PAC is often identical to the GAC used in wastewater treatment. In 1930, Hassler reported that PAC was being used in more than 150 municipal water treatment plants. In this type of use, PAC dosages usually are in the range of 1 to 5 mg/L, although dosages as high as 20 to 30 mg/L have been used in some places for short periods of time when taste and odor problems are severe. PAC is commonly used on a one-time, throwaway basis, with no attempt at recovery or reuse

PAC's principal benefit in water treatment is to remove taste and odor. In some waters, PAC may also remove color or organics that otherwise would interfere with coagulation or filtration. During its widespread use by waterworks for more than 50 years, no harmful effects have been reported.

GRANULAR CARBON

Altogether 46 water treatment plants in the United States are presently using GAC (AWWA, 1979); a partial list is given in Table 2. In these plants, GAC is used to control taste and odor in drinking water. At the Hopewell, Virginia, and Davenport, Iowa plants however, other benefits have been observed by the American Water Works Service Co., especially the reduction of trihalomethanes in finished water.

Because there has been no need for on-site reactivation of carbon, few useful cost data are available for estimating the costs involved in organics removal, which necessitates more frequent renewal of the GAC.

Recently, Manchester, New Hampshire installed a fluidized bed in its water plant for on-site GAC reactivation. Capital costs are available from EPA and the city, but operating and maintenance costs will not be forthcoming until more data are accumulated.

Philadelphia, Cincinnati, and Passaic (New Jersey) are operating pilot GAC projects that will soon yield capital and O&M cost data for water purification.

TABLE 2. GAC INSTALLATIONS IN MUNICIPAL WATER PLANTS IN THE UNITED STATES (partial list)

Location	Bed depth, in.	Capacity, mgd
E. St. Louis, IL*	18	35
Granite City, IL*	18	13
Peoria, IL*	30	30
Kokomo, IN*	20	11
Muncie, IN*	24	8
Richmond, IN*	24	8
Terre Haute, IN*	30	6
Davenport, IA*	24	30
Lexington, KY*	14	20
Ashtabula, OH*	24	4
Marion, OH*	18	7
New Castle, PA*	30	8
Pittsburgh, PA*	30	86
Chattanooga, TN*	30	72
Hopewell, VA*	60	3
Huntington, WV*	30	24
Madison, WV*	18	1
Princeton, WV*	18	3
Weston, WV*	18	1
Montecito Co. Water Dist. Santa Barbara, CA	144	1.5
Del City, OK	36	5.25
Somerset, MA	11	4.5
Pawtucket, RI	18	24
Lawrence, MA	24 30	10
Piqua, OH	18	8
Bartlesville, OK	24	4.5
Winchester, OH	24	1.5
Mt. Clemens, OH	24	7
Manchester, NH	48	15
Passaic, NJ (pilot)		2.2
Cincinnati, OH (pilot)		
Queensbury, MA		
Amesbury, MA		

*19 American Water Works Service Co. system locations presently using GAC, Total capacity, 370 mgd.

SECTION 3

USE OF GAC IN FOOD AND DRINK PROCESSING AND IN OTHER INDUSTRIES

A partial list of carbon reactivation furnace installations in the United States contains many of the largest GAC users in the country (Table 3). Included are seven large sugar refiners and nine large corn syrup refiners who use GAC for decolorizing their food products. The list also includes 15 industries that use GAC to remove organics from their wastewater discharges and 19 cities that use GAC in the advanced treatment of their wastewaters.

GAC has also been used for many years in industrial water purification and in the production of soft drinks, pharmaceuticals, fats and oils, and alcoholic beverages. From 1935 to 1960, the utilization of decolorizing grades of GAC increased from 11,000 to 60,000 tons per year (API, 1969). An even greater use of GAC since 1960 is due in part to the introduction of GAC to municipalities' and sewer districts' wastewater (see Section 4).

TABLE 3. CARBON REACTIVATION FURNACE INSTALLATIONS (partial list)

Installation	Date	Use	
Colorado Springs, CO	1969	Wastewater	Municipal
Rocky River, OH	1972	Wastewater	Municipal
Derry Township, PA	1974	Wastewater	Municipal
Vallejo, CA	1974	Wastewater	Municipal
Santa Clara V.W.D., Palo Alto, CA	1975	Wastewater	Municipal
Tahoe-Truckee San. Dist., CA	1976	Wastewater	Municipal
No. Tonawanda, NY	1976	Wastewater	Municipal
Nassau County, NY	1977	Wastewater	Municipal
South Tahoe P.U.D., CA	1965	Wastewater	Municipal
Orange County (CA) Water District	1972	Wastewater	Municipal
Fitchburg, MA	1972	Wastewater	Municipal
Arlington County, VA	1977	Wastewater	Municipal
Niagara Falls, NY	1977	Wastewater	Municipal
Lower Potomac Plant, VA	1977	Wastewater	Municipal
St. Charles, MO	1977	Wastewater	Municipal
San. Dist. of L.A. County (CA)	1975	Wastewater	Municipal
Courtland, NY	1975	Wastewater	Municipal
Le Roy, NY	1975	Wastewater	Municipal
Washington Suburban San. Comm. (DC)	1971	Wastewater	Municipal
Occoquan, VA	1978	Wastewater	Municipal
Hollytex Carpet Mills, PA	1969	Dye wastewater	
BP Oil, NH	1971	Wastewater	Industrial
Stepan Chemical Co., NY	1972	Wastewater	Industrial
Hercules, MI	1972	Wastewater	Industrial
Amerada Hess, NJ	1973	Wastewater	Industrial
American Aniline, PA	1973	Wastewater	Industrial
American Cyanamid, NJ	1977	Wastewater	Industrial
Esso Research	1973	Wastewater	Industrial
DuPont Deepwater, NJ	1974	Wastewater	Industrial
Republic Steel Corporation	1974	Wastewater	Industrial
Atlantic Richfield, Wilmington, CA	1970	Wastewater	Industrial
Mobay Chem., New Martinsville, W.VA	1972	Wastewater	Industrial
Mobay Chem., Baytown, TX	1973	Wastewater	Industrial
Reichold Chemical	1974	Wastewater	Industrial
TRA, Irving, TX	1976	Wastewater	Industrial
Spreckles Sugar, Mendota, CA	*	Sugar refining	Industrial
Spreckles Sugar, Woodland, CA	*	Sugar refining	Industrial
Florida Sugar Refining, FL	*	Sugar refining	Industrial
Supreme Sugar Co., LA	*	Sugar refining	Industrial
Spreckles Sugar, AZ	*	Sugar refining	Industrial
Spreckles Sugar, Manteca, CA	*	Sugar refining	Industrial
Corn Sweeteners, Cedar Rapids, IA	*	Corn syrup refining	Industrial
Industrial Sugar Co., St. Louis, MO	*	Sugar refining	Industrial
Pennick & Ford, Ltd., Cedar Rapids, IA	*	Corn syrup refining	Industrial
Rhodia Inc., Portland, OR	*	Corn syrup refining	Industrial
Phizer Inc., Groton, CT	*	Corn syrup refining	Industrial
South Coast Corp., L.A., CA	*	Corn syrup refining	Industrial
Anheuser Busch Inc., Lafayette, IN	*	Corn syrup refining	Industrial
American Maize Products, Hammond, IN	*	Corn syrup refining	Industrial
Clinton Corn Proc. Co., Montezuma, NY	*	Corn syrup refining	Industrial
Cargill Inc., Dayton, OH	*	Corn syrup refining	Industrial
PepsiCo, Long Island, NY	*	Sugar refining	Industrial

*Date of installation not available.

SECTION 4

EXTRAPOLATING GAC USE IN MUNICIPAL WASTEWATER RECLAMATION TO WATER TREATMENT

SOUTH LAKE TAHOE

The first plant-scale use of GAC in a municipal wastewater treatment plant was at South Lake Tahoe, California, in 1965. This plant has operated continuously since that time and now has 15 years of operating experience with GAC; the GAC system has processed more than 12 billion gallons of pretreated municipal wastewater. The reclaimed water COD ranges from 10 to 30 mg/L. The South Tahoe installation was a United States Environmental Protection Agency (EPA) Demonstration Plant. For three years, EPA funded the collection of very detailed and complete plant operating data and cost information (Appendix, Case History No. 1).

Except for a few months in 1977-1978 when some carbon was reactivated off-site during an emergency, all carbon has been reactivated at the plant with the use of a multiple hearth furnace. Carbon losses in reactivation have averaged about 8 percent. This means that all of the original carbon has now been replaced by makeup carbon. More significantly, plant experience has now verified the results of bench-scale tests of reactivation (made in 1963)--tests indicating that the GAC could be maintained at or near full adsorptive capacity by means of thermal reactivation until the carbon was eventually all replaced by making up losses from attrition and burning. It has been demonstrated that the GAC has a service life of at least 12 cycles of reactivation under actual full-scale plant operating conditions.

At South Tahoe, the carbon furnace refractories were all replaced after 10 years of service. In 1977-78, due to maladjustment of the burners in the reactivation furnace, excess oxygen was present during reactivation of a considerable volume of GAC. This carbon was overburned and suffered a dramatic loss (over 50 percent) in adsorptive capacity. Fortunately, it was possible to fully restore the adsorptive capacity of the carbon in one pass through the furnace, once the burners were re-adjusted properly. During this emergency, some off-site reactivation of GAC was necessary. This is the only major difficulty encountered in 15 years of operation of the GAC system. Corrosion of the exhaust gas scrubber has been somewhat of a problem, especially when breakpoint chlorination is practiced before GAC adsorption. Exhaust gas scrubbers should be fabricated from 316 SS (Stainless Steel) where such corrosive conditions prevail. Also the 50 psi, 304 SS carbon column inlet and outlet screens are being replaced by 100 psi, 316 SS over a period of years due to corrosion and mechanical distortion. The average service life of the original screens will probably exceed 15 years by the time all are replaced.

OTHER WASTEWATER INSTALLATIONS

Water reclamation plants constructed at the Orange County (CA) Water District (Water Factory 21), the Upper Occoquan (VA) Sewer Authority, and the Tahoe-Truckee (CA) Sanitation Agency (Nos. 6, 3, and 2, respectively) have the same configuration as the South Tahoe plant both in respect to the type of GAC facilities provided and the high degree of pretreatment afforded. All of these plants operate successfully with few GAC system problems. As might be expected with second and third generation designs, these later plants embody some improvements over the original South Tahoe installation, although there are no major changes or deviations.

Although there are many other successful applications of GAC in advanced waste treatment (AWT) plants, the experience with GAC in AWT in some places has, unfortunately been poor. These failures in AWT applications have not stemmed from deficiencies in the basic GAC processes or in organics adsorption and thermal reactivation, but, rather, from mechanical problems.

OPERATIONAL PROBLEMS

In discussing the operational problems encountered with GAC systems, those problems associated specifically with sewage treatment must be distinguished from general problems that might be encountered with any type of GAC system. Many problems with GAC in wastewater treatment will not occur in water purification. For example, in water treatment, fewer or no problems could be expected with excessive slime growths, hydrogen sulfide gas production, or corrosion from adsorbed organics released during carbon regeneration.

Some of the types of problems encountered with GAC systems in wastewater treatment include:

- inadequate carbon transfer and feed equipment,
- undersized slurry and transfer lines,
- failure to provide for venting air from backwash lines with destruction of filter bottoms and disruption of GAC,
- failure to house or otherwise protect automatic control systems, from the weather,
- inadequate means for continuous, uniform feed to furnace, which result in temperature fluctuations, inconsistent reactivation efficiency, and wasted energy,
- location of furnace and auxiliary drive motors in areas of very high ambient temperature (e.g., above top of furnace), and
- the use of nozzles in filter and carbon contactor bottoms, which produced major failures in carbon systems just as they have for many years in water filtration plants. Their use is risky.

Common problems related to wastewater treatment have been growth of biological organisms in the carbon contactors and development of anaerobic conditions with the production of corrosive hydrogen sulfide. Both of these problems have been successfully circumvented by providing adequate flow through the columns or frequent backwashing. Failure to provide adequate pretreatment has caused column clogging and mud balls with the need for more frequent backwashing.

Corrosion has been a problem with some of the GAC systems. The furnace system, transfer piping, and storage tanks are susceptable components. Many operations require frequent replacement of the rabble arms and teeth and replacement of the hearths every few years. At one installation, titanium or ceramic coated rabble teeth were no more resistant to corrosion than stainless steel teeth. In one case, the corrosion problem in the furnace was solved by eliminating the use of auxiliary steam during reactivation. In another case, corrosion was linked to fluctuating temperatures in the hearths caused by irregular feed to the furnace and frequent startup and shutdown. These problems can be partially remedied by better operation and avoided by better engineering design.

In several industrial applications, the wastewater itself has been highly corrosive. In these cases, the contactors have been subject to corrosion. At Spreckles Sugar, the epoxy linings in the columns must be replaced every 3 years; Republic Steel also replaces its column linings on a regular basis. Public water supply sources would not be expected to consist of corrosive water.

By properly applying the best current engineering design knowledge and practices for GAC systems, these rather serious problems might be avoided. When water works engineers apply GAC to produce high quality drinking water, they should make the most of the experiences of the consultants for industry and wastewater agencies.

EXTENDING WASTEWATER TREATMENT EXPERIENCE TO WATER TREATMENT SYSTEMS

Caution must be observed in extrapolating GAC cost data from operating industrial installations and municipal wastewater treatment plants to the design of water works. The purpose for using GAC in each of these types of applications is generally the same--to remove organics. There are, however, important differences. In industry, the GAC serves to remove a rather narrow band of organics--color molecules--from a viscous liquid. In wastewater treatment, the GAC removes (with or without biological activity) a broad spectrum of organic substances from water as measured by BOD, COD, and TOC. In water treatment, the objectives of GAC treatment are not completely defined at this time. For raw waters with color or taste and odor problems, using GAC unquestionably improves drinking water from an aesthetic standpoint. In many cases, the cost of GAC may be warranted for either of these purposes alone. For the great number of water systems without color or taste and odor problems, the only concern with respect to organics is the possible health effects over long periods of time from ingesting trace quantities of organics that may cause cancer.

Public health officials and water works managers still disagree as to whether the health risks that may be involved in the presence of minute traces of organics in drinking water are sufficient to warrant the cost of GAC treatment. A major problem is that the potentially harmful organics in drinking water have not all been identified at this time, and many of those that have been tagged as suspect have widely different adsorptive characteristics. Some adsorb readily on GAC; others do not.

GAC loading rates at exhaustion of adsorptive capacity vary widely among the different potentially hazardous organics. This affects the length of service life of GAC before carbon reactivation or replacement is necessary--a determining factor in GAC treatment costs. Similarly, the reactivation times and temperatures for thermal reactivation of GAC saturated with different organics also differ, and all are not known at this time. Again, this has an important bearing on GAC treatment costs. Because of the widely varying adsorptive and reactivation characteristics of trace organics on GAC in water supplies, pilot plant tests of both adsorption and reactivation are mandatory preludes to treatment system design at this time.

Over a period of years, general, average design parameters may emerge from the results of pilot plant studies and demonstration projects, but this time is not yet at hand. Once the GAC design parameters for water treatment have been established from pilot tests for a particular water source, then the knowledge and experience from other GAC installations in industry and wastewater plants can be put to good use. Carbon dosages, GAC contact times, and spent carbon reactivation times and temperatures can be determined. Contactor sizes can be calculated and furnace sizes and fuel requirements can be determined. Transport facilities for GAC in water treatment can be the same as for other types of GAC installations provided the differences in quantities and possible differences in the viscosities of carbon slurries due to any slime growths are taken into account. Also, with the GAC design parameters pinpointed as a result of pilot plant studies, construction costs can be accurately estimated based on the costs of existing installations in AWT and industry. The estimates cannot, however, be based on an MGD capacity basis; rather, they must be based on adsorption and reactivation data applicable to each specific installation.

Selecting the most economical number of contactors for a water system of a certain size involves the same principles as are used for other systems. Because of shipping regulations, factory-fabricated contactor vessels are generally limited to about 12-ft maximum diameter. For large capacity installations, a smaller number of field-erected steel vessels or poured-in-place concrete vessels may be less costly.

Because upflow contactors provide all of the advantages of countercurrent operation with respect to carbon savings, they are favored for most types of service. The exception is water treatment. In this case, downflow is used because the discharge of carbon fines in the effluent (a characteristic of upflow columns) is avoided.

Cost estimates must be evaluated on the same basis as all other estimates of construction cost; there is no reason that they should be more or less accurate than estimates made for the rest of the treatment plant. Fifteen percent is generally accepted as being an allowable difference between costs estimated from construction plans and the best bid received from contractors. With good pilot plant data and with proper application of cost data from existing GAC installations, preliminary cost estimates for GAC treatment of public water supplies should be accurate enough for planning purposes.

The extrapolation of wastewater treatment experience with GAC to the design of water treatment systems is a task for trained, experienced, engineering professionals. Even then, the foregoing discussions are intended to be no more than an introduction to the subject.

SECTION 5

DESIGNING GAC ADSORPTION AND REACTIVATION SYSTEMS FOR WATER TREATMENT

The following discussion is devoted to some of the procedures and details for developing the design basis and costs for GAC water treatment systems from pilot plant test results and information from full-scale applications.

GAC SYSTEM COMPONENTS

Systems utilizing GAC are rather simple. In general, they provide for contact between the carbon and water to be treated for the length of time required to obtain the necessary removal of organics; reactivation or replacement of spent carbon; and transport of makeup or reactivated carbon into the contactors and transport of spent carbon from the contactors to reactivation or hauling facilities.

PILOT PLANT TESTS

Despite the simplicity of GAC systems, laboratory and pilot plant tests are needed to select the carbon and the most economical plant design for both water and wastewater treatment projects. Pilot column tests make it possible to determine treatability; select the best carbon for the specific purpose based on performance; determine the required empty bed contact time; establish the required carbon dosage, which, together with laboratory tests of reactivation, will determine the capacity of the carbon reactivation furnace or the necessary carbon replacement costs; and determine the effects of influent water quality variations on plant operation. During pilot testing, the influence of longer carbon contact times on reactivation frequency can be measured; these measurements allow costs to be minimized through a proper balance of these two design factors.

DESIGN OF PILOT GAC COLUMNS

Detailed information, including a list of materials, on the design and construction of pilot GAC columns is presented in Appendix C of EPA's "Interim Treatment Guide For Controlling Organic Contaminants in Drinking Water Using GAC." Appendix B of EPA's "Interim Treatment Guide" describes the analytic methodology for monitoring pilot column tests. Also included are data on the adsorbability of various organic compounds; the performance of GAC in their removal; information on the use of multiple-hearth, infrared, fluidized bed, and rotary kiln furnaces for reactivation of spent GAC; and example calculations for balancing added costs of increased contact time versus savings (if any) from less frequent reactivation.

SIMILARITIES AND DIFFERENCES IN THE USE OF GAC IN WATER AND WASTEWATER TREATMENT

FREQUENCY OF REACTIVATION

One of the principal differences in costs for GAC treatment between water and wastewater is the more frequent reactivation required in water purification due to earlier breakthrough of the organics of concern. In wastewater treatment, GAC may be expected to adsorb 0.30 to 0.55 lb COD/lb carbon before the carbon is exhausted. From the limited amount of data available from research studies and pilot plant tests (most of it unpublished), it appears that some organics of concern in water treatment may breakthrough at carbon loadings as low as 0.05 to 0.25 lb organic/lb carbon. The actual allowable carbon loading or carbon dosage for a given case must be determined from pilot plant tests. Costs taken from wastewater cost curves, which are plots of flow in mgd versus cost (capital or operation and maintenance costs), cannot be applied directly to water treatment. Allowance must be made in the capital costs for the different reactivation capacity needed and in the operation and maintenance costs for the actual amount of carbon to be reactivated or replaced.

Because the organics adsorbed from water are generally more volatile than those adsorbed from wastewater, the increased reactivation frequency due to lighter carbon loading may be partially offset, or more than offset, by the reduced reactivation requirements of the more volatile organics. The times and temperatures required for reactivation may be reduced due to both the greater volatility and to the lighter loading of organics on the carbon.

From the limited experimental reactivations to date, it appears that reactivation temperatures may be less than the 1650° to 1750°F required for wastewater carbons. The shorter reactivation times required for water purification carbons may allow the number of hearths in a multiple hearth reactivation furnace to be reduced. Also, less fuel may be required for reactivation. These factors must be determined on a case-by-case basis.

GAC CONTACTORS

Selection of the general type of carbon contactor to be used for a particular water treatment plant application may be based on several considerations including economics and the judgement and experience of the engineering designer. The choice generally would be made from three types of downflow vessels:

1. Deep-bed, factory-fabricated, steel pressure vessels of 12-ft maximum diameter. These vessels might be used over a range of carbon volumes from 2,000 to 50,000 ft^3.

2. Shallow-bed reinforced concrete, gravity-filter-type boxes may be used for carbon volumes ranging from 1,000 to 200,000 ft^3. Shallow beds probably will be used only when short contact times are sufficient or when long service cycles between carbon regenerations can be expected from pilot plant test results.

3. Deep-bed, site-fabricated, large (20- to 30-ft) diameter, open concrete or steel, gravity tanks may be used for carbon volumes ranging from 6,000 to 200,000 ft^3, or larger.

These ranges overlap, and the designer may very well make the final selection based on local factors, other than total capacity, that affect efficiency and cost.

The AWT experience with GAC contactors may be applied to water purification if some differences in requirements are taken into account. The required contact time must be determined from pilot plant test results. Although contactors may be designed for a downflow or upflow mode of operation and upflow packed beds or expanded beds provide maximum carbon efficiency through the use of countercurrent flow principles, the leakage of some (1 to 5 mg/L) carbon fines in upflow carbon column effluent make downflow carbon beds the preferred choice in most municipal water treatment applications. At the Orange County Water Factory 21, upflow beds were converted to downflow beds to successfully correct a problem with escaping carbon fines. This full-scale plant operating experience indicates that leakage of carbon fines is not a problem in properly operated downflow GAC contactors.

Single beds or two beds in series may be used. Open gravity beds or closed pressure vessels may be used. Structures may be properly protected steel or reinforced concrete. In general, small plants will use steel, and large plants may use steel or reinforced concrete.

Sand in rapid filters has, in some instances, been replaced with GAC. In situations where contact times are short and GAC regeneration or replacement cycles are exceptionally long (several months or years) as may be the case in taste and odor removal, this may be a solution. However, with the short cycles anticipated for most organics, conventional concrete-box-style filter beds may not be well suited to GAC contact. Deeper beds may be more economical in first cost and provide more efficient use of GAC. In converted filter boxes, possible corrosion effects of GAC on existing metals, such as surface wash equipment and metal nozzles in filter bottoms, must be taken into account. Beds deeper than conventional filter boxes, or contactors with greater aspect ratios of depth to area, provide much greater economy in capital costs. The contactor cost for the needed volume of carbon is much less. In water slurry, carbon can be moved from contactors with conical bottoms easily and quickly and with virtually no labor. Flat-bottomed filters of a type that require labor to move the carbon unneccesarily add to carbon transport costs. The labor required to remove carbon from flat-bottomed beds varies considerably in existing installations from a little labor to a great deal, depending upon the design of the evacuation equipment.

For many GAC installations intended for precursor organic removal or synthetic organic removal, specially designed GAC contactors should be installed. Contactors should be equipped with flow measuring devices. Separate GAC contactors are especially advantageous where GAC treatment is required only part of the time during certain seasons because they then can be bypassed when not needed, possibly saving unnecessary exhaustion and reactivation of GAC.

Tremendous cost savings can be realized in GAC treatment of water through proper selection and design of the carbon contactors. The design of carbon contactor underdrains requires experienced expert attention.

CARBON CONTACTOR UNDERDRAINS

Although good proven underdrain systems are available, often they have not been used, and there have been numerous underdrain failures due to poor design. Some of the designs used in the past have failed in many installations for conventional filter service, and they continue to be misapplied to GAC contactors as well as filters.

GAC REACTIVATION OR REPLACEMENT

Spent carbon may be removed from contactors and replaced with virgin carbon, or it may be reactivated either on-site or off-site. The most economical procedure depends on the quantities of GAC involved. For larger volumes, on-site reactivation is the answer. For small quantities of carbon, replacement or off-site reactivation will probably be most economical.

Carbon may be thermally reactivated to very near virgin activity. Carbon burning losses may, however, be excessive under these conditions. Experience in industrial and wastewater treatment indicates that carbon losses can be minimized (held to 8 to 10 percent per cycle) if the activity of reactivated carbon (as indicated by the iodine number) is held at about 90 percent of the virgin activity. To remove certain organics, there may be no decrease in actual organics removal despite a 10 percent drop in iodine number.

THERMAL REACTIVATION EQUIPMENT

GAC may be reactivated in a multiple-hearth furnace, a fluidized bed furnace, a rotary kiln, or an electric infrared furnace. Spent GAC is drained dry in a screen-equipped tank (40 percent moisture content) or in a dewatering screw (40 to 50 percent moisture) before being introduced to the reactivation furnace. Dewatered carbon is usually transported by a screw conveyor. Following thermal reactivation, the GAC is cooled in a quench tank. The water-carbon slurry may then be transported by means of diaphragm slurry pumps, eductors, or a blow-tank. The reactivated carbon may contain fines produced during conveyance; these fines should be removed in a wash tank or in the contactor. Maximum furnace temperatures and retention time in the furnace are determined by the amount (lb organics/lb carbon) and nature (molecular weight or volatility) of the organics adsorbed.

Off-gases from carbon reactivation present no air pollution problems provided they are properly scrubbed. In some cases, an afterburner may also be required for odor control.

Despite recent advances in the design of infrared and fluidized bed reactivation furnaces, the multiple hearth furnace is still the simplest, most reliable, and easiest to operate for GAC reactivation. The infrared and fluid bed units still have problems to be worked out; experience with the multiple hearth equipment has already solved these problems. Still, it is necessary with all four types of furnaces to specify top quality materials to suit the conditions of service and to see that these materials are properly installed. Corrosion resistance is important in the furnace itself and especially in all auxiliaries to the furnace.

REQUIRED FURNACE CAPACITY

The principal cost differences between GAC treatment of water and wastewater may lie in the capital cost of the furnace and in the O&M cost for carbon reactivation. As already explained, the two principal differences between carbon exhausted in wastewater treatment and carbon exhausted in water purification are that water purification carbons are likely to be easier to regenerate (less time in furnace and lower furnace temperatures) and more lightly loaded (greater volume of carbon to be reactivated per pound of organics removed). Accurate estimates of GAC costs require knowledge and consideration of these two factors. To repeat, it is not possible to use AWT cost curves based on mgd throughput or plant capacity to obtain costs for water treatment. Differences in reactivation requirements must be taken into account.

CARBON TRANSPORT AND GAC PROCESS AUXILIARIES

There can be large differences in O&M costs for GAC systems depending on the method selected for carbon transport. Hydraulic transport of GAC in water slurry by gravity or use of water pressure is simple, easy, inexpensive, rapid, and uses very little labor. Moving dry or dewatered carbon manually or with mechanical means involving labor can be very difficult, time consuming, and costly.

SECTION 6*

THE COST OF GAC IN WATER TREATMENT

DEVELOPING COST CURVES

Little information is available concerning the cost and performance of GAC for drinking water treatment. As discussed in the previous sections, most of the data available on GAC performance have been acquired from wastewater and industrial applications. An attempt has been made, however, to extrapolate from these existing systems and to develop standardized and flexible cost data that can be used to prepare cost estimates for GAC systems that treat drinking water.

Design Cost Information

Much of the analysis and cost information contained in this section are based on a four-volume report prepared for EPA (Culp/Wesner/Culp, 1979). Twelve cost curves, discussed in detail in the above report, were developed specifically for GAC applications.**

Derivation of Cost Curves

Relating Costs to Design Parameters--
The construction cost for each unit process was presented as a function of the process design parameter. This parameter was determined to be the most useful and flexible under varying conditions, such as loading rate, detention time, or other conditions that vary because of designers preference or regulatory agency requirements. For example, the contactor construction cost curves were presented in terms of cubic feet of contactor volume, an approach that allows various empty bed contact times (EBCT) to be used. Contactor O&M curves were presented in terms of square feet of surface area, since O&M requirements are more appropriately related to surface area rather than contactor volume. Reactivation facility cost curves were presented in terms of square feet of hearth area for the multiple hearth furnance and pounds per day of reactivation capacity for the other reactivation variables. This allows the loading per square foot of hearth area to be varied for the multiple hearth furance and for design of reactivation furnaces at carbon reactivation rates less than the

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* Section 6 was prepared and written by Dr. Robert M. Clark, EPA, Cincinnati, Ohio.

**Cost curves were developed for 12 GAC processes (Culp/Wesner/Culp, 1979): Large systems, 1 to 200 mgd, include gravity carbon contactors (concrete construction); gravity carbon contactors (steel construction); pressure carbon contactors; conversion of sand filters to carbon contractors; granular activated carbon (material cost); multiple hearth granular carbon reactivation; infrared granular carbon reactivation; fluid bed granular carbon reactivation; atomized suspension powdered carbon reactivation; fluidized bed powdered carbon reactivation; and off-site regional carbon reactivation. Small systems, 2,500 to 1,000,000 gpd, include package granular activated carbon columns.

reactivation capacity. This approach provides greater flexibility in the use of the cost curves than if the costs were related to water flow through the treatment plant.

Methods Used to Develop Cost Curves--

The construction cost curves were developed by using equipment cost data supplied by manufacturers, cost data from actual plant construction, unit takeoffs from actual and conceptual designs, and published data. The costs (developed by Culp/Wesner/Culp) were then check by a second consulting engineering firm (Zurheide-Herrmann, Inc.), using an approach similar to an approach used by a general contractor in determining a construction bid. Any discrepancies existing between the initial estimate and the second estimate were then resolved.

Construction Cost Components--

The costs for eight principal construction components were developed and then aggregated to give the construction cost for each unit process. These eight principal components were: (1) excavation and sitework, (2) manufactured equipment, (3) concrete, (4) steel, (5) labor, (6) pipe and valves, (7) electrical and instrumentation, and (8) housing. These eight categories also provide enough detailed information to permit accurate future cost updating.

The construction cost curves are not the final capital cost for the unit process. The construction cost curves do not include costs for general contractor overhead and profit, engineering, legal, fiscal, and administration interest during construction. These items are all more directly related to the total cost of a project, rather than the cost of the individual unit processes. They, therefore, are most appropriately added following summation of the cost of the individual unit processes, if more than one unit process is required. Example calculations are included below to illustrate the recommended method for these costs.

Operation and Maintenance Components--

O&M requirements were developed for (1) building related energy, (2) process energy, (3) maintenance material, and (4) labor. The separate determination of building energy makes it possible to allow for geographic variations in this component. Energy requirements were presented in kilowatt-hours per year for electricity, standard cubic feet per year for natural gas, and gallons per year for diesel fuel. Labor was presented in hours per year, allowing local cost variations to be incorporated into the O&M cost calculations. Maintenance material cost was in dollars per year, but did not include the cost of chemicals. Chemical costs were added separately, as will be shown in the example presented later.

Example Cost Curves

For the majority of the unit processes, three separate figures were used to present construction and O&M curves. The first graph presented the construction cost; the second graph, energy (electrical, natural gas, and diesel fuel) and maintenance material requirements; and the third graph, labor requirements and total O&M cost. Figures 1, 2, and 3 present the cost curves developed for pressure carbon contactors.

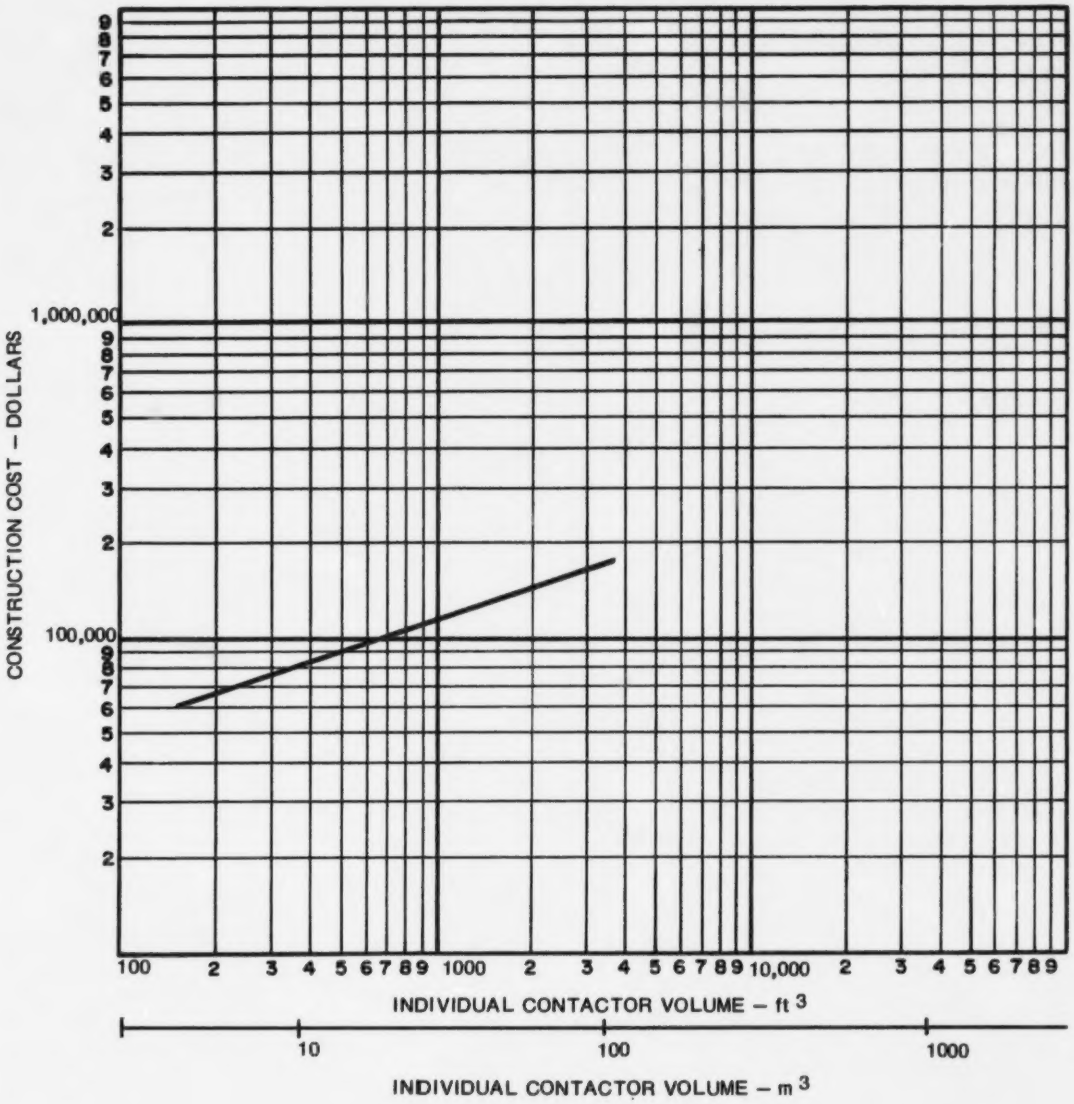

Figure 1. Construction cost for pressure carbon contactors (from Culp, Wesner, Culp, 1979).

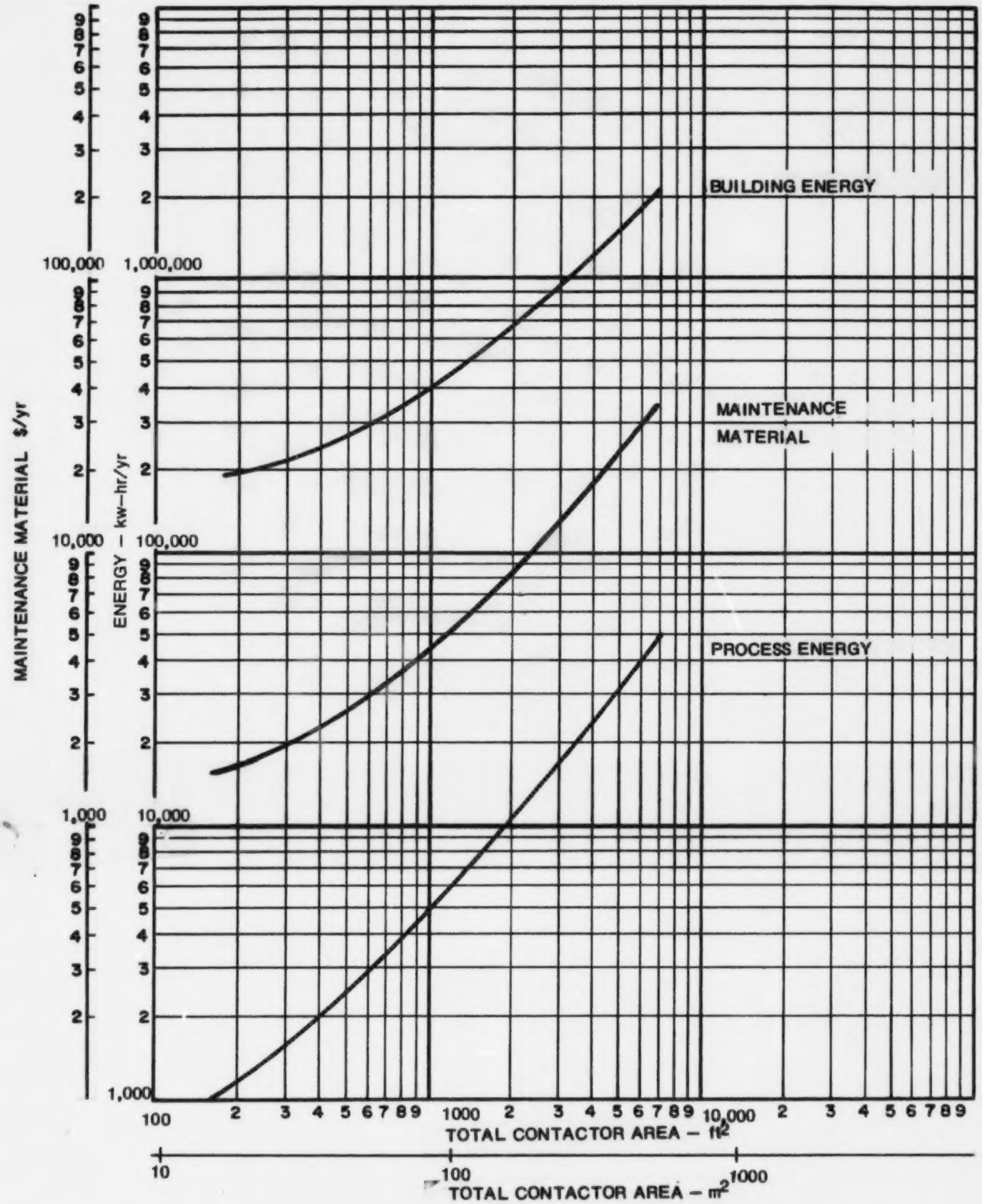

Figure 2. Typical activated carbon column installation (from Culp, Wesner, Culp, 1979).

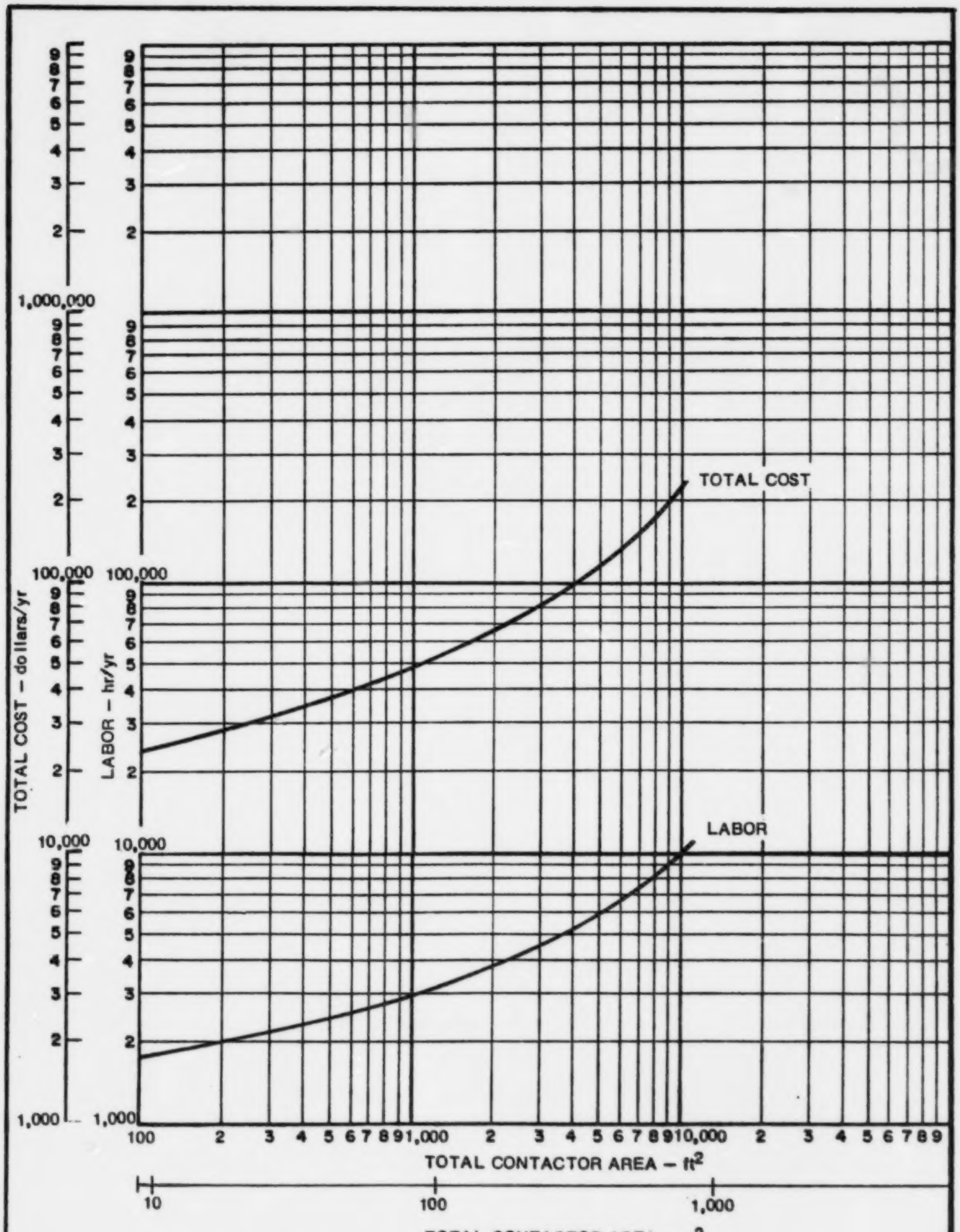

Figure 3. Operation and maintenance requirements for pressure carbon contactors - labor and total cost.

Updating Cost Curves

Use of Indices for Updating Construction Costs--

For many engineering purposes, a single cost index, such as the Engineering News Record's (ENR) Construction Cost Index (CCI) may be used to update construction costs. When this approach provides sufficient accuracy, a single index is certainly the simplest and easiest approach. In the case of water treatment construction costs, especially those for carbon treatment, use of the CCI is not recommended because the construction components used in its development are not related to those required for water treatment plants. For example, the CCI does not include process equipment or electrical equipment for instrumentation and control. For water treatment plants, the use of several indices is recommended such as the Bureau of Labor Statistics (BLS) (Bureau of Labor Statistics, 1979), indices in conjunction with ENR Building Cost Index and Skilled Labor Wage Index.

The tabulation below shows the indices recommended for each of the eight categories used to derive construction costs. This approach allows updating to be done proportionally to changes in the cost of each component. The eight construction cost components represent the major items of material and labor affecting the cost of water treatment plant construction.

CONSTRUCTION COST COMPONENT	INDEX
Excavation and Sitework	ENR Wage Index (Skilled Labor)
Manufactured Equipment	BLS General Purpose Machinery and Equipment Code 114
Concrete	BLS Concrete Ingredients - Code 132
Steel	BLS Steel Mill Products Code 1013
Labor	ENR Wage Index (Skilled Labor)
Pipes and Valves	BLS Valves and Fittings Code 114901
Electrical and Instrumentation	BLS Electrical Machinery and Equipment - Code 117
Housing	ENR Building Cost Index

The principal disadvantages of this approach are the lack of geographical specificity of the BLS indices and the extra effort involved in using seven rather than a single index.

TABLE 4. COST CALCULATION AND OPERATION AND MAINTENANCE REQUIREMENTS FOR A 100 MGD PRESSURE GRANULAR ACTIVATED CARBON PLANT (from Culp/Wesner/Culp, 1979)

System and design criteria	Design parameter	Construction cost - $	Operating parameter	Energy kwhr/yr	Natural gas scf/yr	Maintenance material-$/yr	Labor hr/yr
Gravity, Steel Contactor - 18 min. EBCT, 30' dia, 5 gpm/ft^2	11,489 ft^3/ Contactor	$ 4,503,440	183,824 ft^3	3,720,810	0	21,590	8,362
Initial Carbon Charge - 26 lb/ft^3	4,779,400 lb	2,746,810	--	0	0	0	0
Backwash Pumping - 12 gpm/ft^2	7,520 gpm	101,710	--	0	0	0	0
Multiple Hearth Carbon Reactivation Furnace	1,173 ft^2	2,467,640	1,173 ft^2	1,111,310	158,149,050	12,740	13,824
Make-up Carbon, 6% regen., 5 times/yr	--	0	1,433,820 lb/yr	0	0	857,740	0
Subtotal	--	$ 9,819,600	--	4,832,120	158,149,050	892,070	22,186
Sitework, Interface Piping, Roads @ 5%	--	490,980	--	--	--	--	--
Subsurface Consideration	--	0	--	--	--	--	--
Standby Power	--	0	--	--	--	--	--
Total Construction Cost	--	$10,310,580	--	--	--	--	--
General Contractor's Overhead and Profit	--	927,950	--	--	--	--	--
Subtotal	--	$11,238,530	--	--	--	--	--
Engineering @ 10%	--	1,123,850	--	--	--	--	--
Subtotal	--	$12,362,380	--	--	--	--	--
Land, 20 acres @ $2,000/acre	--	40,000	--	--	--	--	--
Legal, Fiscal, and Administrative	--	79,070	--	--	--	--	--
Interest During Construction - 8%	--	1,108,240	--	--	--	--	--
TOTAL CAPITAL COST	--	$13,589,690	--	--	--	--	--

TABLE 5. ANNUAL COSTS FOR 110-MGD GRAVITY, STEEL GAC PLANT (from Culp/Wesner/Culp, 1979)

Item	Total cost/year
Amortized capital @ 8%, 20 yrs	$ 1,384,110
Labor, 22,186 hr @ $10/hr (total labor costs including fringes and benefits)	221,860
Electricity, 4,832,120 kwhr @ $0.03/kwhr	144,960
Natural gas, 158,149,050 scf @ $0.00175/scf	276,760
Maintenance material	892,070
TOTAL ANNUAL COST*	$ 2,919,760

$$\text{*Cents per 1,000 gal treated} = \frac{\$2,919,760\ (100)}{77,000\ (365)}$$

$$= 10.4¢/1,000 \text{ gal}$$

construction have been applied. It should be emphasized that all of the calculations in this section are based on hypothetical conditions, and the reader should be aware that the design criteria and costs presented are general in nature and are not necessarily applicable to all plants with the same capacity and operating conditions. However, considerable insight and useful information for preliminary costing estimates can be obtained from the these data.

GAC USE IN WATER TREATMENT

The previous discussion was devoted to the development of cost curves that can be used for preliminary cost estimating. This following discussion deals with the application of these curves estimating the cost of using GAC in drinking water treatment.

Treating water with GAC involves (AWWA, 1979) two major and separate process operations: filtration and reactivation. The water comes in contact with activated carbon by passing through a structure filled with activated carbon granules. Impurities are removed from the water by adsorption when sufficient time is provided for this process. The structure can be either a water treatment filter shell in which the filter media has been replaced with GAC, or an independent activated carbon adsorption system. A separate activated carbon adsorption system usually consists of a number of columns or basins, used as contactors, that are connected to a reactivation system. After a period of use, the activated carbon's adsorptive capacity is exhausted, and it must then be taken out of service, either by replacement with new activated carbon or being reactivated by combustion of the organic adsorbate. Activated carbon is routinely added to the system to replace that lost during hydraulic transport and reactivation. These losses include both losses caused by physical deterioration and by burning during the reactivation process.

The cost analysis contained in this section will include both situations--the use of GAC as a replacement for existing filtration media (sand replacement) and as a separate adsorption system (post-filter adsorption). On-site multiple hearth reactivation will be assumed. Standard levels of key design parameters will be set at predetermined levels and then one variable at a time will be changed to determine its effect on system cost.

The need to consider the cost of separate GAC contactors is eliminated if GAC is replacing sand in existing filters. For the purposes of the sand replacement analysis, a water treatment plant is assumed to consist of an integral number of 1 mgd filters with an effective volume of 18.5 ft x 18.5 ft x 2.5 ft or 856 ft^3. Design parameters assumed for the sand replacement systems are shown in Table 6, and design assumptions for post-filter adsorber systems are shown in Tables 6 and 7.

Note that for sand replacement, a GAC loss of 10 percent per reactivation cycle is assumed, but a GAC loss of only 6 percent per cycle is assumed for post-filter adsorbers. These two assumptions are intended to reflect differences in the operation of the two systems. Sand replacement systems are labor intensive and increase the possibility of GAC loss because the activated carbon is changed manually. In post-filtration systems, the activated carbon is assumed to be changed hydraulically, leading to fewer possibilities for handling losses. Table 8 shows the unit costs for both types of systems for 1, 5, 10, 100, and 150 mgd plants at 70 percent capacity.

The costs shown in Table 8 can be further divided into reactivation costs for sand replacement systems and into reactivation and contactor costs for the post-filter adsorbers. Table 9 contains amortized capital and O&M costs for sand replacement and post-filter adsorption systems. As can be seen, a large portion of the capital cost for both processes is associated with reactivation. Post-filter adsorption is more capital intensive in general than is the sand replacement mode.

Sensitivity Analysis

In this section, the effect of changing variable levels will be considered. Standard values shown in Table 6, which yield the unit costs shown in Tables 8 and 9, will be assumed. The effect of changing the design parameter around the standard values will be examined for GAC sand replacement and post-filter adsorbers separately (Clark et al, 1977). A comparison will be made between 100 mgd, sand replacement, and filter-adsorption systems.

Figure 4 shows the cost of both sand replacement and post-filter adsorption systems versus plant capacity,* based on the assumptions in Tables 7 and 8. Figures 5 and 6 show amortized capital costs and the O&M for both system types, respectively. Significant scale economies exist with respect to plant capacity. Similar relationships hold with respect to loading rate as well. Unit costs will rise dramatically for a plant of a given capacity as loading rate decreases. Figure 7 shows the effect of reactivation frequencies on a total

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*Note: The proposed regulation (Part B) was to apply to utilities serving 75,000 people or more (approximately 10 mgd) (Culp/Wesner/Culp, 1979).

TABLE 6. DESIGN PARAMETERS FOR GRANULAR ACTIVATED CARBON

Design parameter	Unit of measure
Sand replacement:	
Activated carbon cost	\$0.65/lb
Activated carbon loss per reactivation cycle	10%
Fuel cost	\$1.75/million Btu (\$1.66/th J)
Electric power cost	\$0.04/kwhr
Construction Cost Index	325
Producers Price Index	243.8
Direct hourly wage rate	\$10/hr
Amortization rate	8%
Amortization period	20 yrs
Volume per filter	856 ft^3
Loss in adsorptive capacity	0%
Design capacity	70%
Empty bed contact time	9 min
Reactivation frequency	Every 1.2 months
Post-filter adsorption:	
Activated carbon cost	\$0.65/lb
Activated carbon loss per reactivation cycle	6%
Fuel cost	\$1.75/million Btu (\$1.66/th J)
Electric power cost	\$0.04/kwhr
Construction Cost Index	325
Producers Price Index	
Direct hourly wage rate	\$10/hr
Amortization rate	8%
Amortization period	20 yrs
Loss in adsorptive capacity	0%
Design capacity	70%
Empty bed contact time	18 min
Reactivation frequency	Every 2.4 months

TABLE 7. ASSUMPTIONS FOR SEPARATE POST-FILTRATION SYSTEMS

	Design capacity, mgd				
Item	1	5	10	100	150
Number of contactors	3	6	12	40	60
Diameter of contactors (ft)	8	12	12	20	20
Depth of contactors (ft)	13	13	13	14	14
Volume of GAC per contactor (ft^3)	653.1	1469.5	1469.5	4396.0	4396.0
Minimum empty bed contact time (min)	18	18	18	18	18

TABLE 8. AMORTIZED CAPITAL AND OPERATING AND MAINTENANCE COST FOR GAC SYSTEM (¢/1,000 gal)*

Item	Design capacity, mgd				
	1	5	10	100	150
Amortized capital cost:					
Sand replacement	30.2	10.9	7.4	2.3	1.9
Filter adsorber	35.7	15.4	11.8	5.9	5.5
Operating and maintenance cost:					
Sand replacement	21.4	14.0	12.5	9.3	8.9
Filter adsorber	24.1	13.6	11.6	8.0	7.6
Total cost:					
Sand replacement	51.6	24.9	19.9	11.6	10.8
Filter adsorber	59.8	29.0	23.4	13.9	13.1

*To convert from ¢/1,000 gal to ¢m^3 multiply by 0.26.

TABLE 9. CONTACTOR AND REACTIVATION COSTS FOR GAC SYSTEMS

Item	Costs, ¢/1,000 gal				
	1 mgd	5 mgd	10 mgd	100 mgd	150 mgd
Amortized capital cost:					
Sand replacement					
Reactivation	29.3	10.1	6.7	1.7	1.3
Carbon	0.9	0.8	0.8	0.7	0.6
Filter adsorber					
Reactivation	29.3	10.2	6.7	1.7	1.3
Contactor	4.5	3.5	3.5	2.9	2.9
Carbon	2.0	1.6	1.5	1.3	1.3
Operating and maintenance cost:					
Sand replacement					
Reactivation	21.4	14.0	12.5	9.3	8.9
Filter adsorber					
Reactivation	18.8	11.3	9.9	7.0	6.6
Contactor	5.3	2.3	1.7	1.0	1.0
Totals:					
Sand replacement					
Reactivation	50.7	24.2	19.2	10.9	10.2
Filter adsorber					
Reactivation	48.1	21.5	16.6	8.6	7.9
Contactor	9.8	5.8	5.2	3.9	3.9

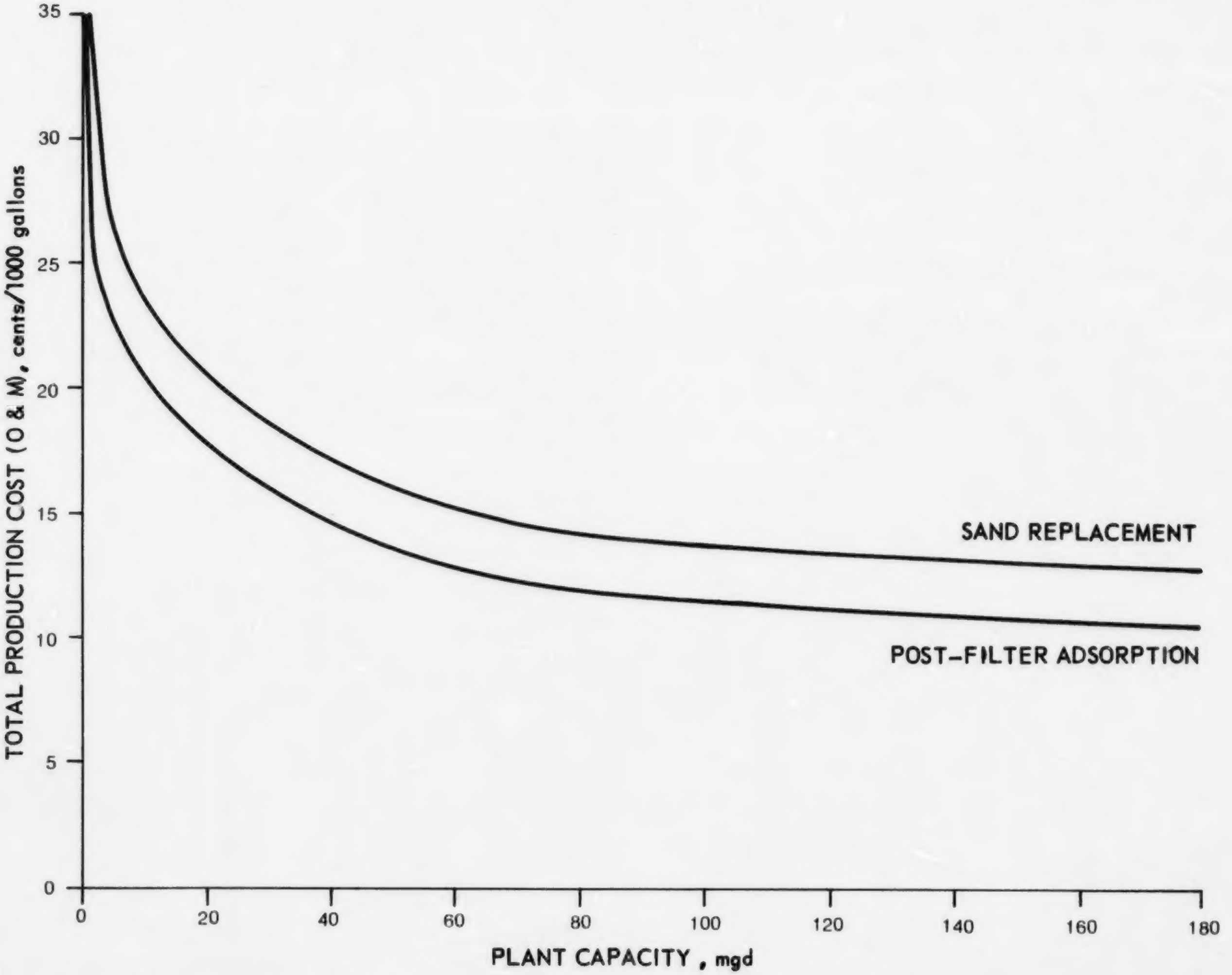

Figure 4. Total production cost versus plant capacity for post-filter adsorption and sand replacement systems.

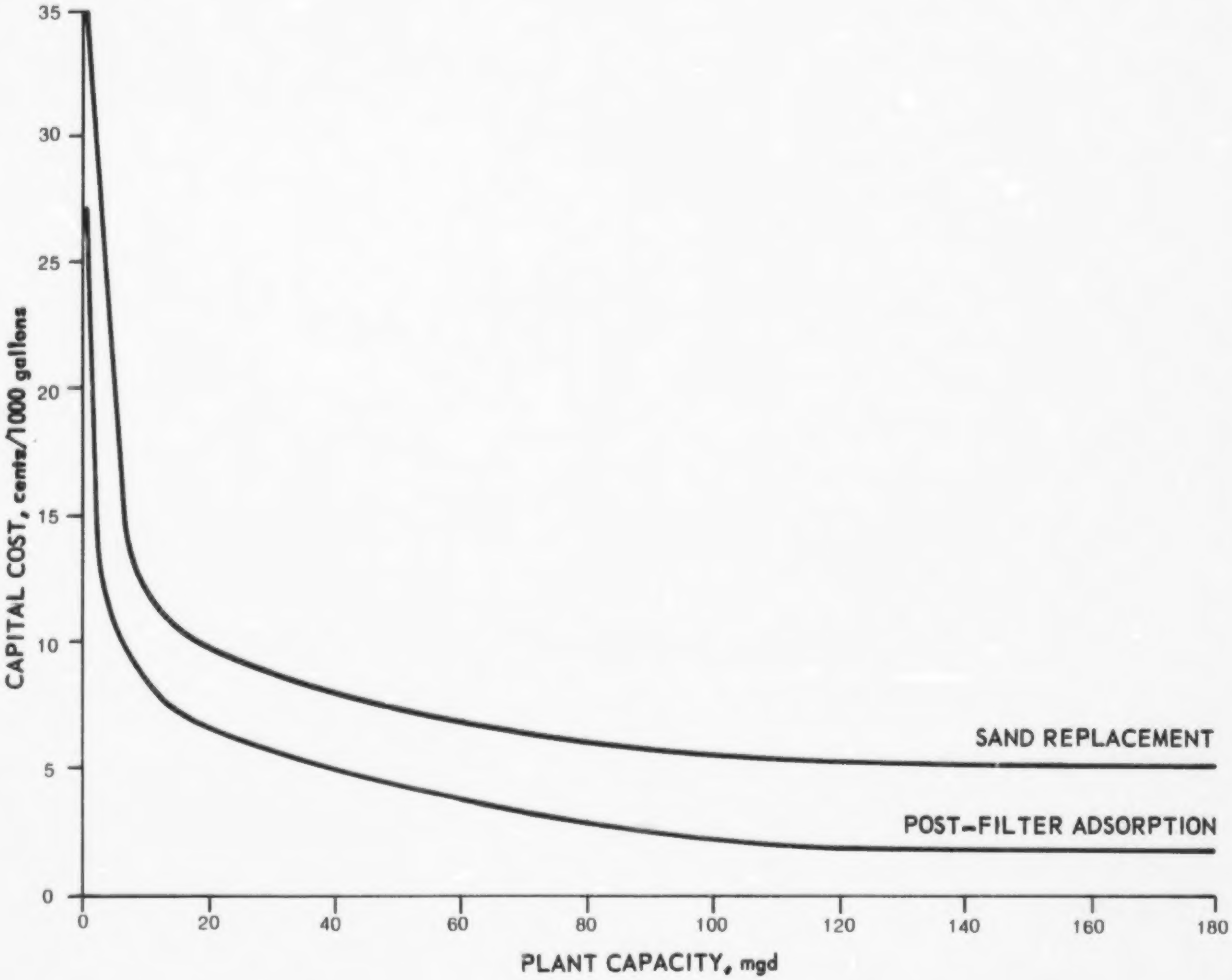

Figure 5. Capital cost versus plant capacity for post-filter adsorption and sand replacement systems.

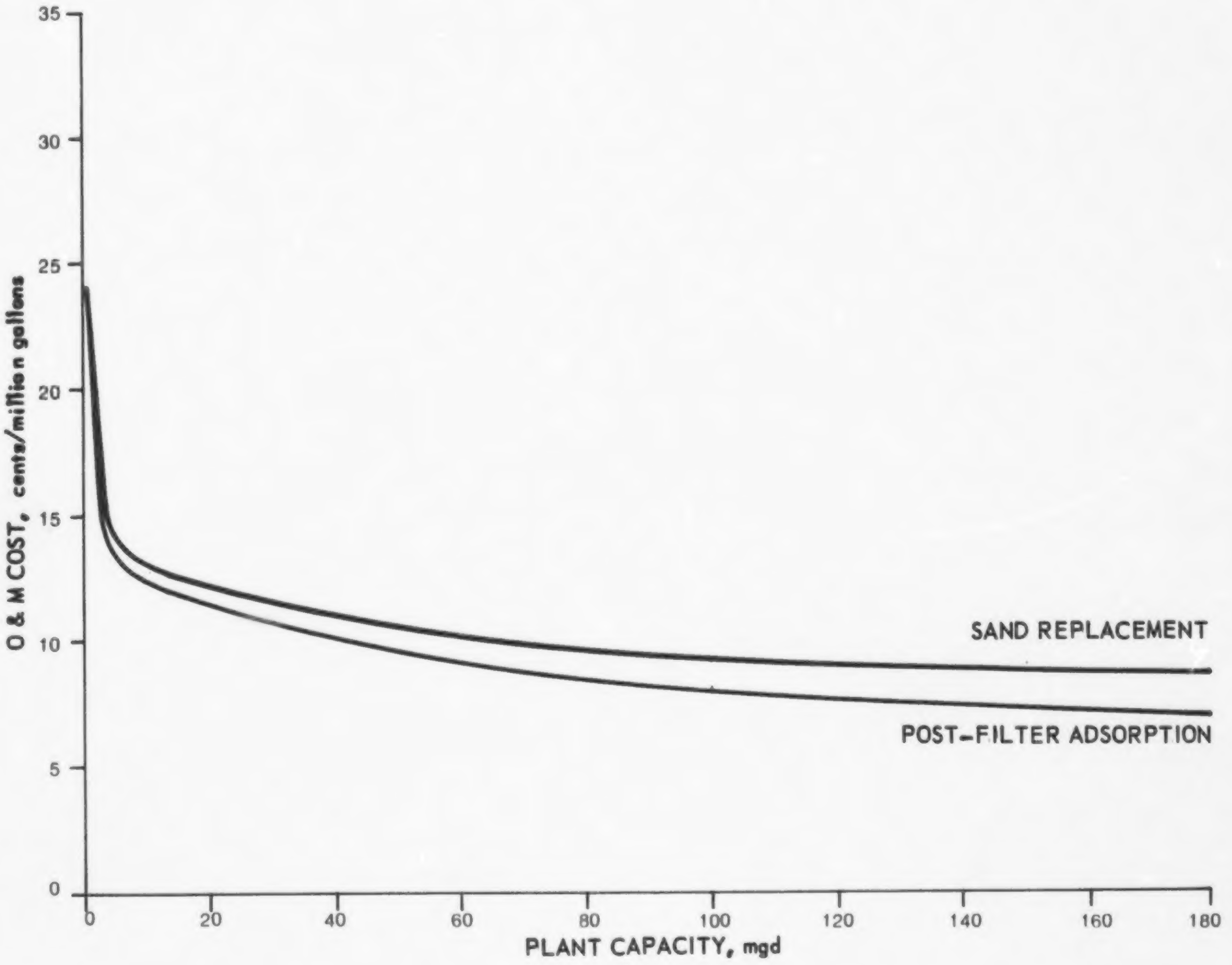

Figure 6. O&M cost versus plant capacity for post-filter adsorber and sand replacement systems.

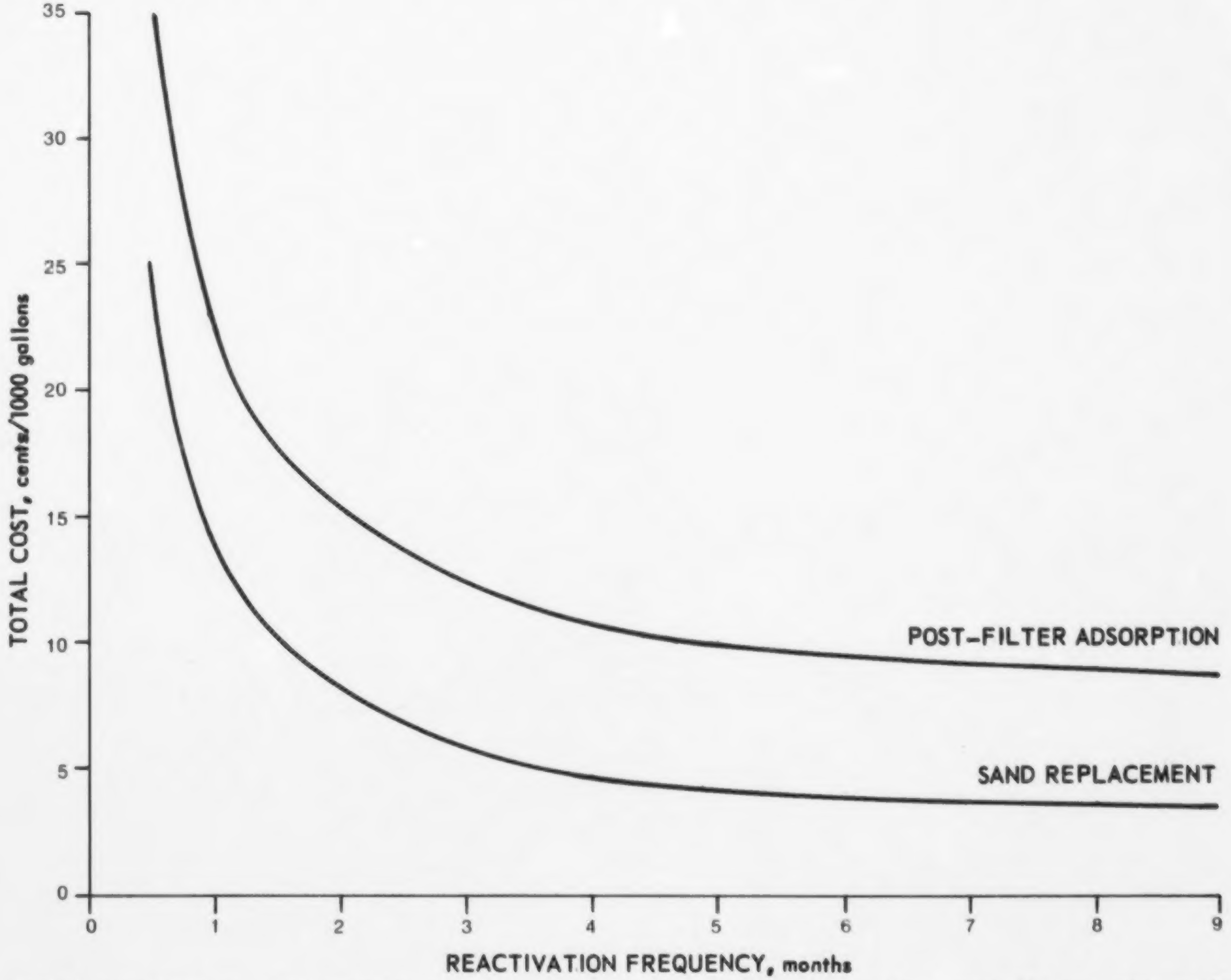

Figure 7. Total production cost versus reactivation frequency in months for post-filter adsorption and sand replacement systems (100 mgd).

production cost for both post-filter adsorption and sand replacement systems--cost rises dramatically with increased reactivation.

Operating and Maintenance

Some operating variables influence only O&M cost, some only amortized capital cost, and some both O&M and capital cost. The first set of variables to be examined are those that influence O&M cost only: hourly wage rate in \$/hr; activated carbon loss per reactivation cycle in %; fuel cost in \$/therm; Producers Price Index; and electrical power cost in \$/kwh. This analysis is performed for 1, 5, 10, 100 and 150 mgd systems operating at 70 percent of capacity.

Figure 8 shows that changes in hourly wage rate have a greater impact on O&M cost in small plants than in larger plants. For example, it can be seen that as the hourly wage rate increases from \$6/hr to \$10/hr, the O&M cost for a 1 mgd plant increases from slightly over 17¢/1,000 gal to slightly less than 19.5¢/1,000 gal. The same wage rate changes in a 10 mgd plant increases the O&M cost from approximately 11¢/1,000 gal to 11.6¢/1,000 gal. Figure 9 shows the changes in O&M cost resulting from increases in activated carbon loss per reactivation cycle. Figures 10 through 12 show changes in O&M cost resulting from changes in fuel cost, Producers Price Index, and electrical power cost for sand replacement systems.

Capital Cost Effect

The group of variables that influence amortized capital cost are: Construction Cost Index; amortization interest rate; and amortization period in years. Figure 13 illustrates the impact of varying construction cost index on amortization capital cost in ¢/1,000 gal. Figure 14 shows the effect of changing interest rates on amortized capital cost. Figure 15 shows the effect of changing amortization period. As can be seen, the impact of changing these parameters is also greater for small than for large plants.

O&M and Capital Cost Effect

Several of the standard design parameters affect both amortized capital and O&M cost: activated carbon cost and reactivation frequency. Figures 16 and 17 show the effect of activated carbon cost variations on capital and O&M cost and Figures 18 and 19 show the effect of changing reactivation frequency.

Key Variables

The previous analyses show that the cost of GAC systems are more sensitive to some variables than to others. Most variables have a greater impact on smaller than on large systems. The only exception is the affect of reactivation frequency on capital cost.

O&M Effects--

The variables having the most effect on O&M costs are system size, reactivation frequency, activated carbon loss, and activated carbon cost. Small changes in these variables may have large effects on system cost. Fuel cost and wage rate have a smaller effect on system cost. System cost is relatively

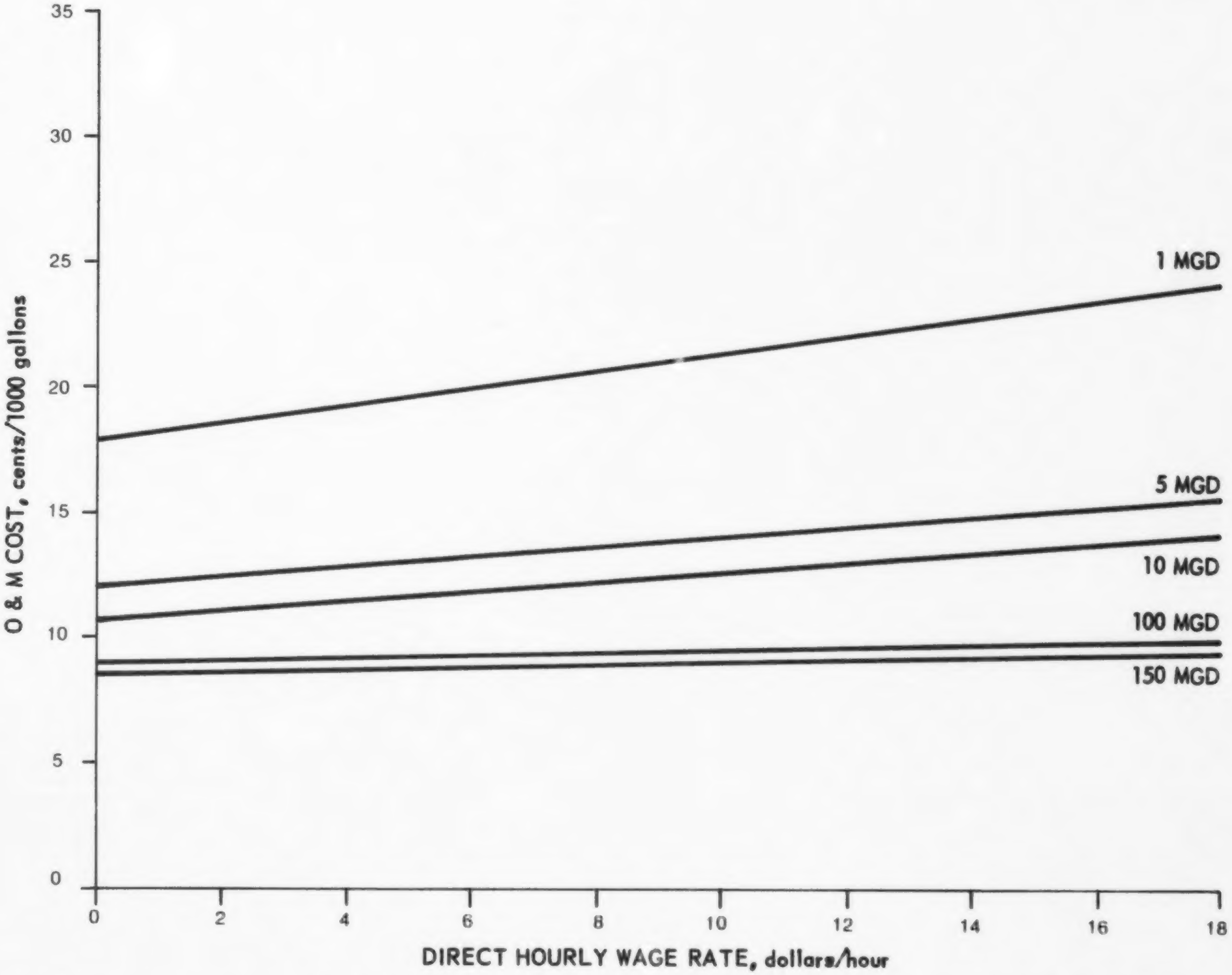

Figure 8. O&M cost versus wage rate for 1, 5, 10, 100, and 150 mgd sand replacement systems.

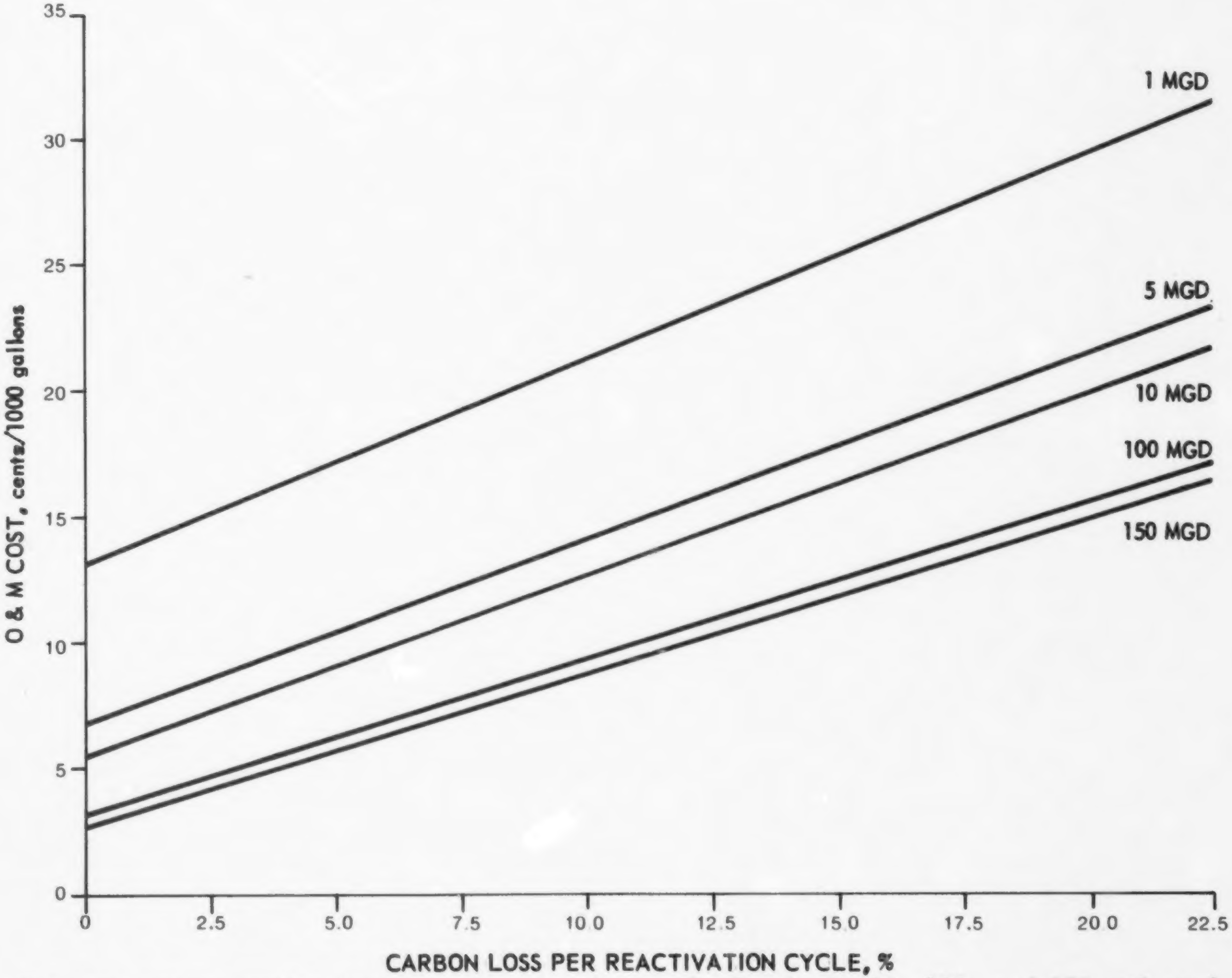

Figure 9. O&M cost versus carbon loss per reactivation cycle for 1, 5, 10, 100, and 150 mgd sand replacement systems.

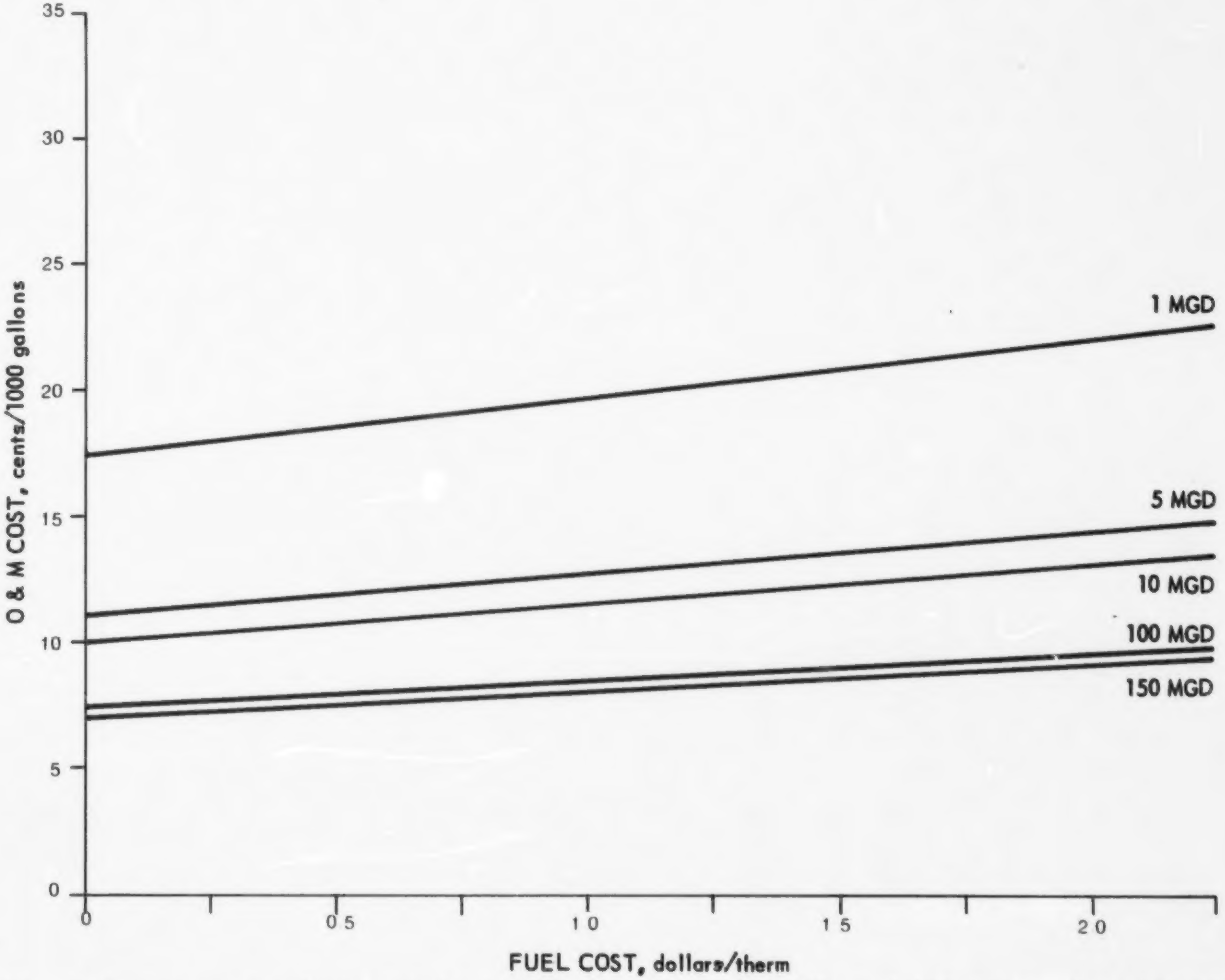

Figure 10. O&M cost versus fuel cost in $/therm for 1, 5, 10, 100, and 150 mgd sand replacement systems.

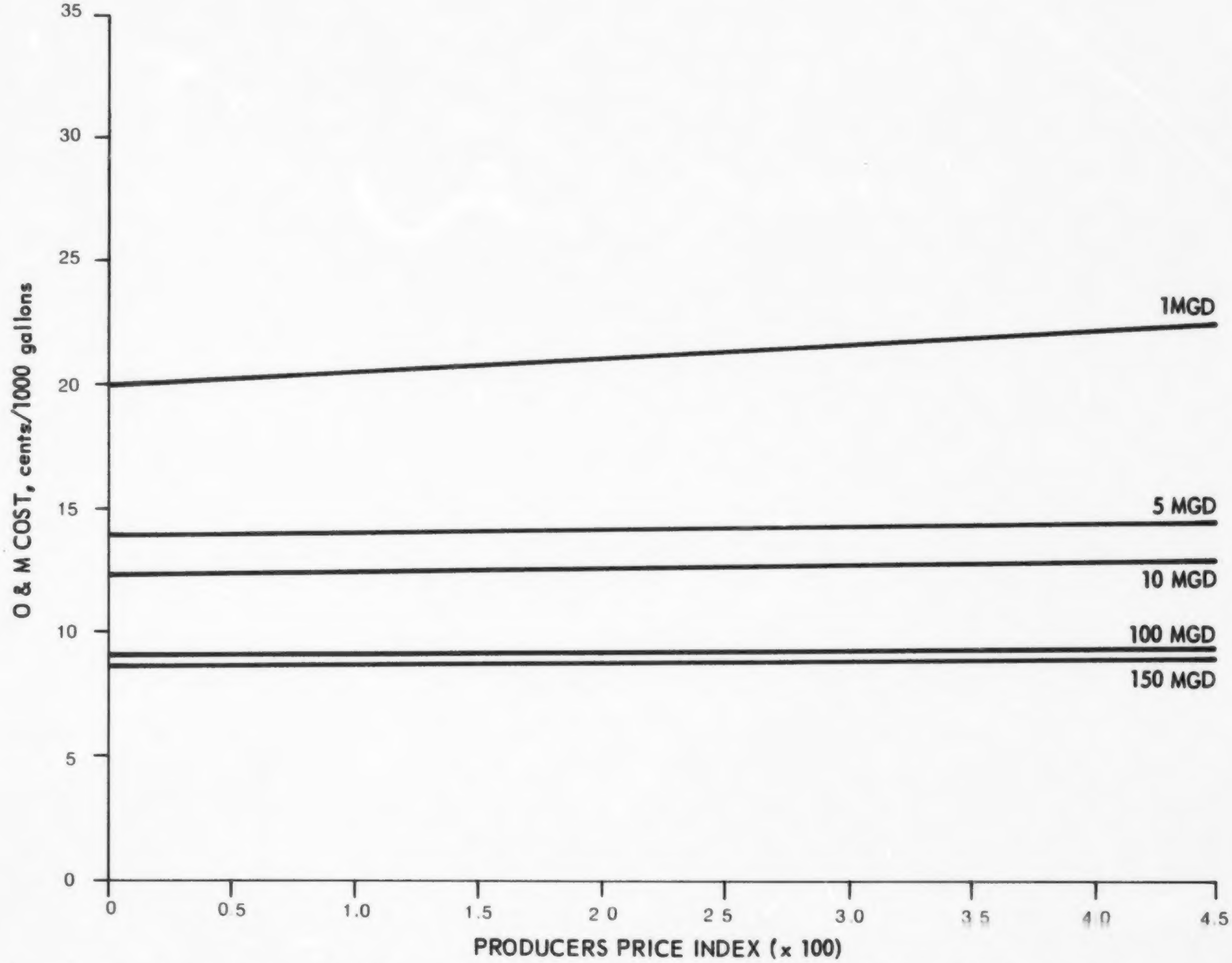

Figure 11. O&M cost versus producers price index for 1, 5, 10, 100 and 150 mgd sand replacement systems.

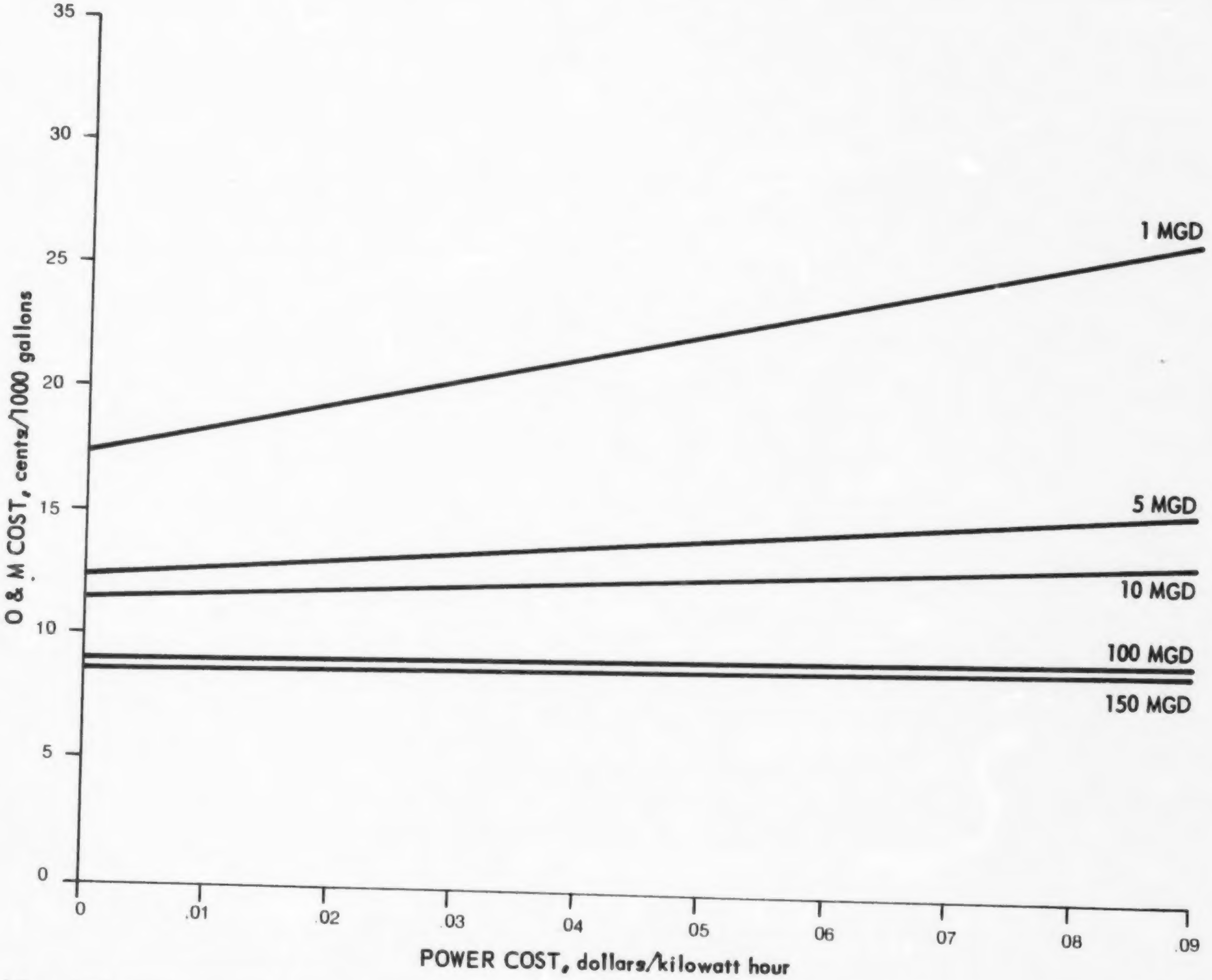

Figure 12. O&M cost versus power cost for 1, 5, 10, 100, 150 mgd sand replacement systems.

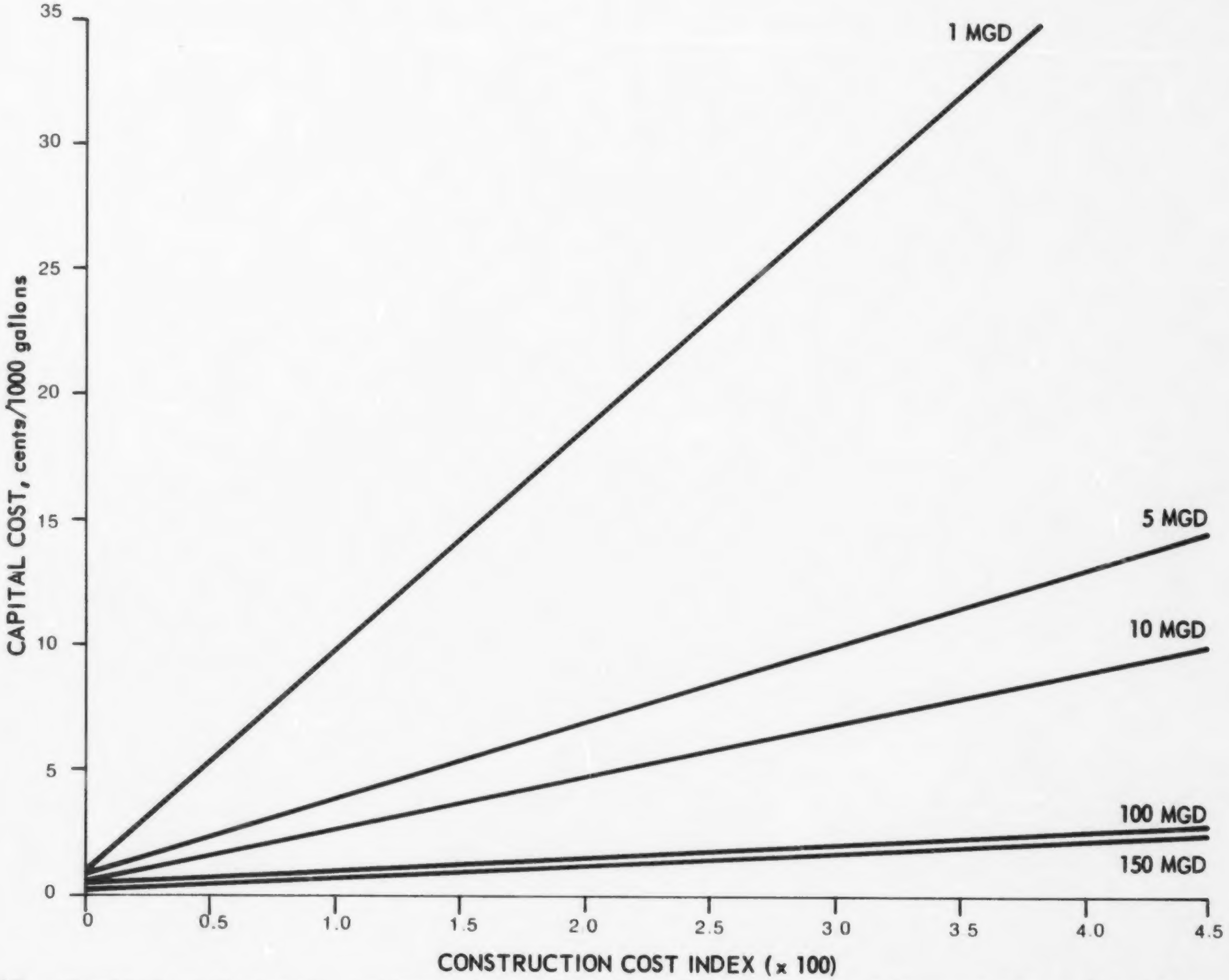

Figure 13. Capital cost versus construction cost index for 1, 5, 10, 100, and 150 mgd sand replacement systems.

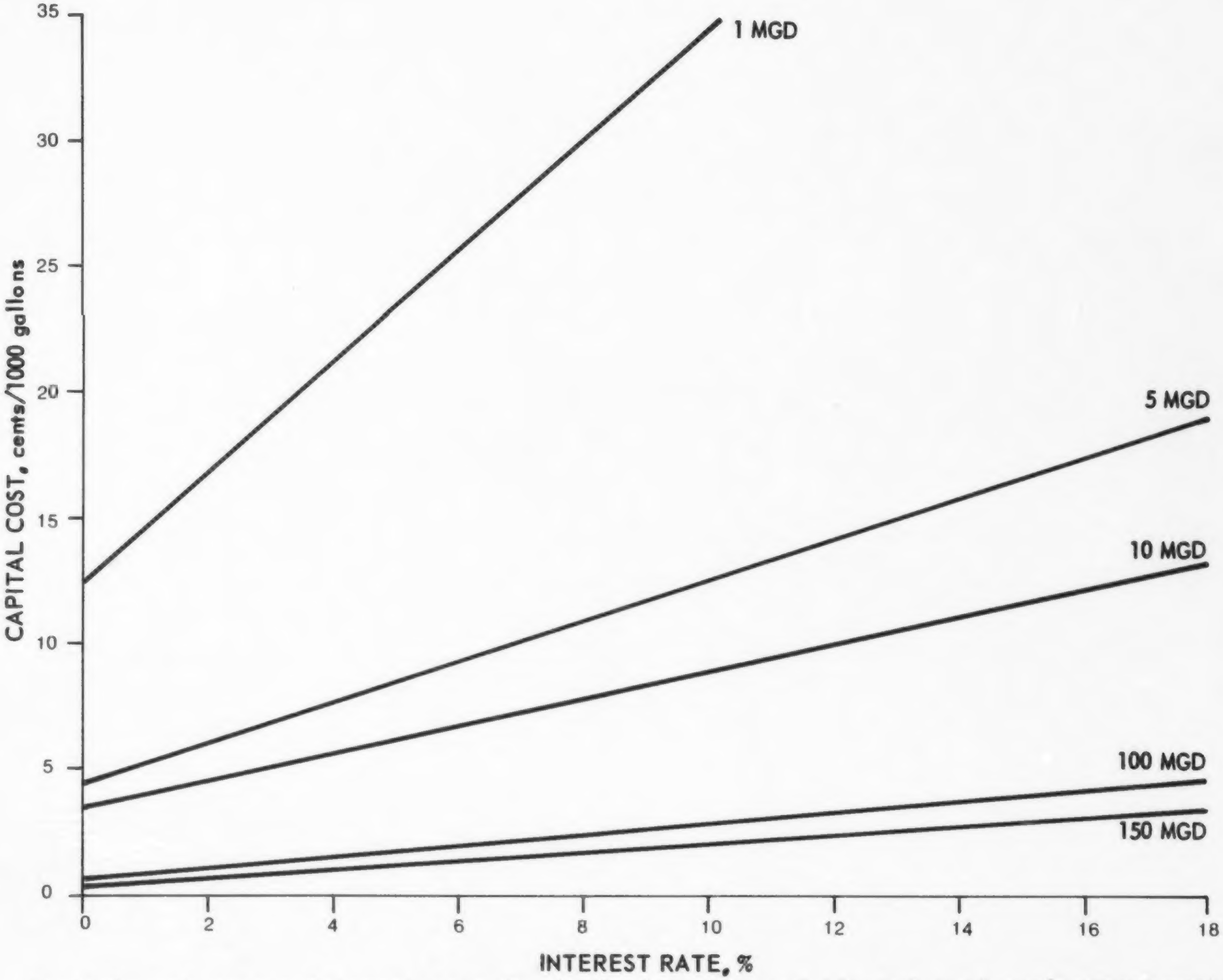

Figure 14. Capital cost versus interest rate for 1, 5, 10, 100, and 150 mgd sand replacement systems.

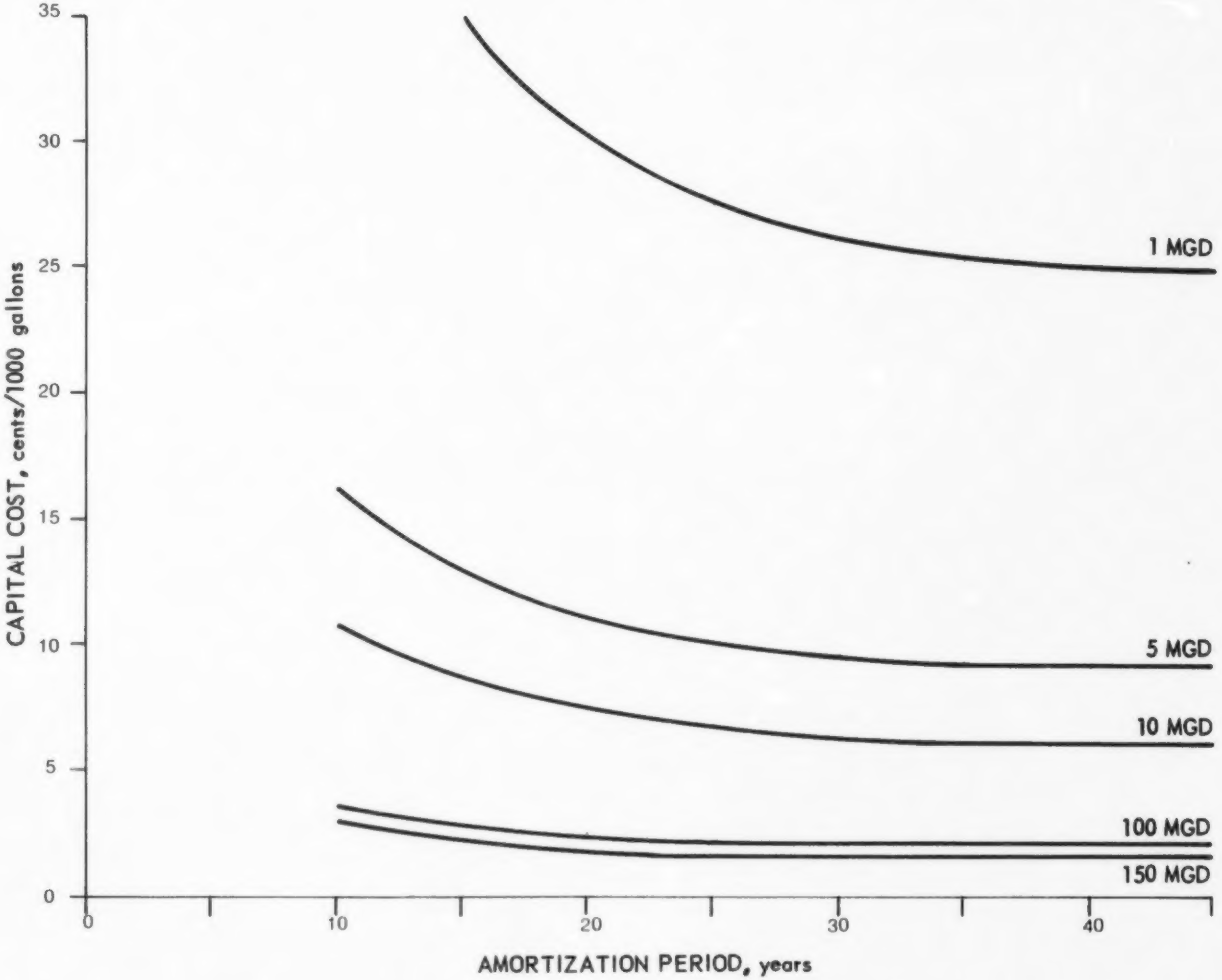

Figure 15. Capital cost versus amortization for 1, 5, 10, 100, and 150 mgd sand replacement system.

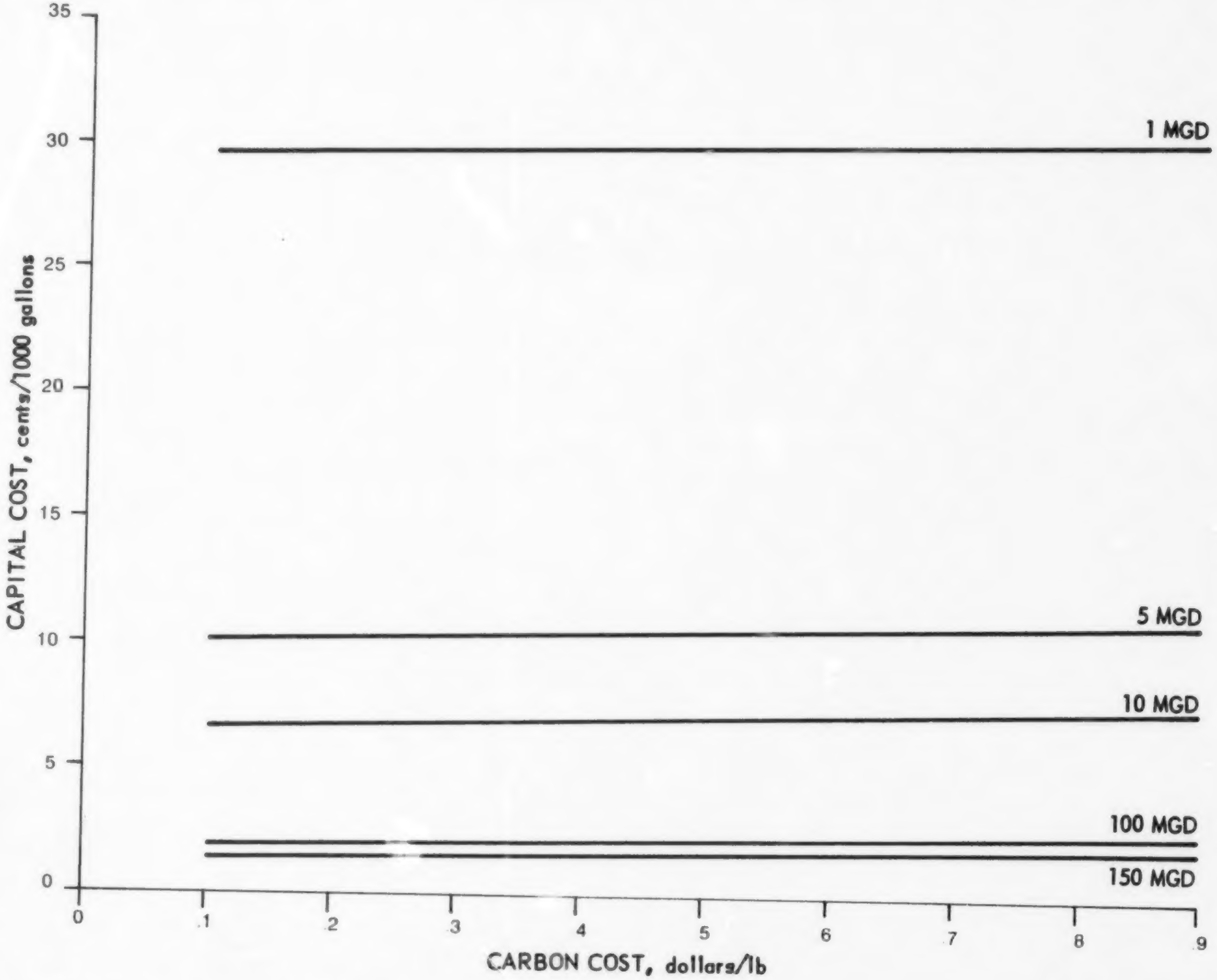

Figure 16. Capital cost versus carbon cost for 1, 5, 10, 100, and 150 mgd sand replacement systems.

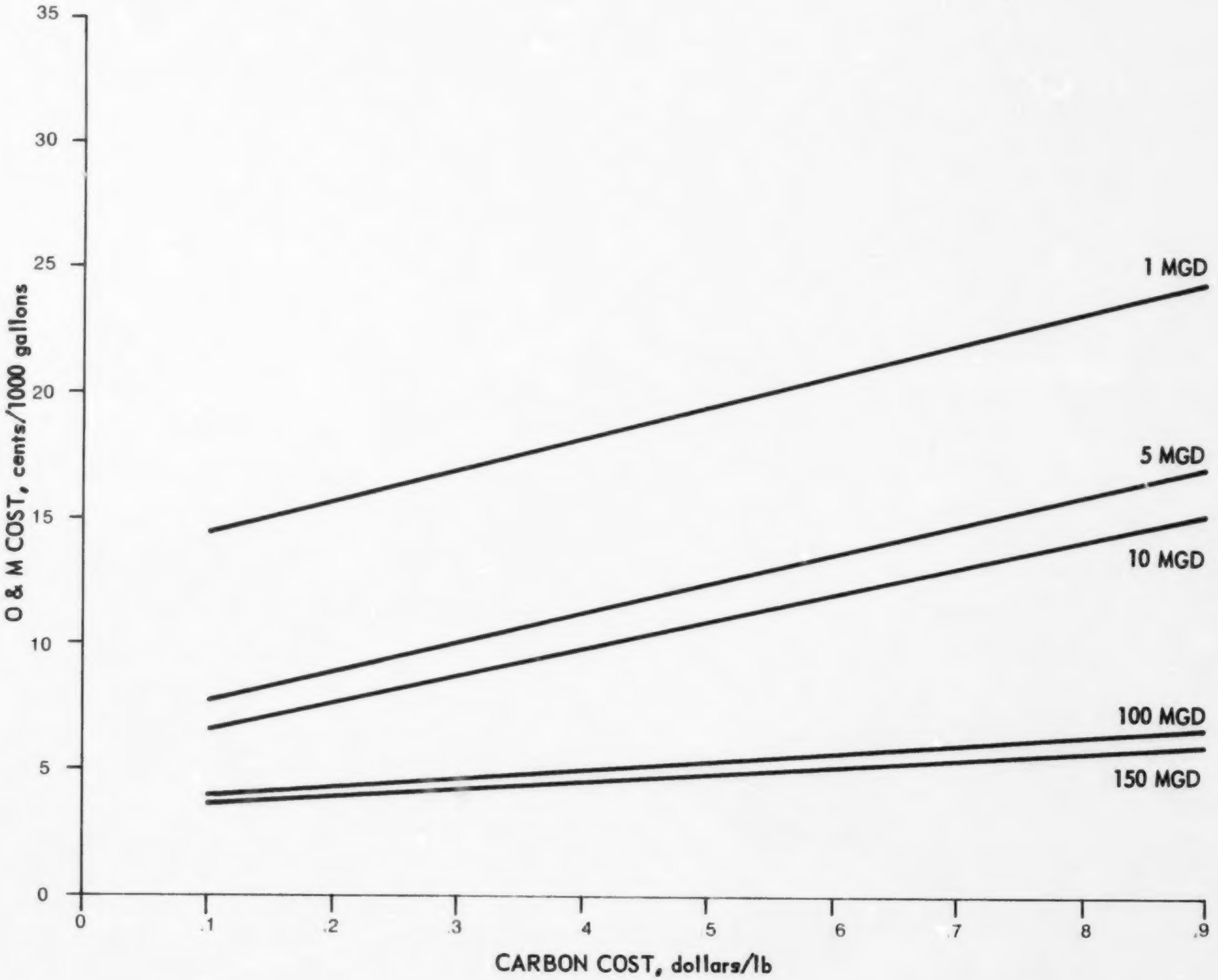

Figure 17. O&M cost versus carbon cost for 1, 5, 10, 100, and 150 mgd sand replacement system.

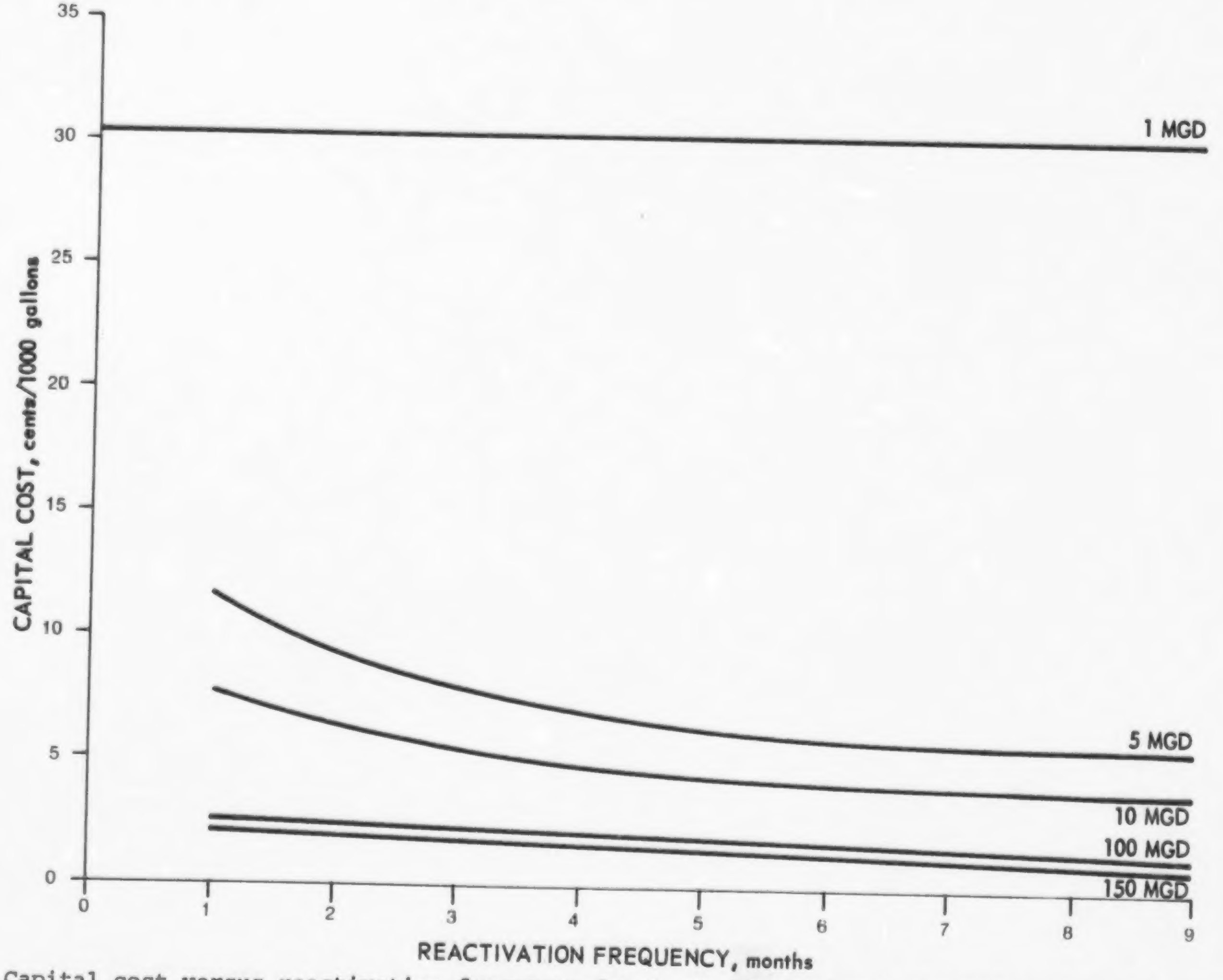

Figure 18. Capital cost versus reactivation frequency for 1, 5, 10, 100, and 150 mgd sand replacement systems.

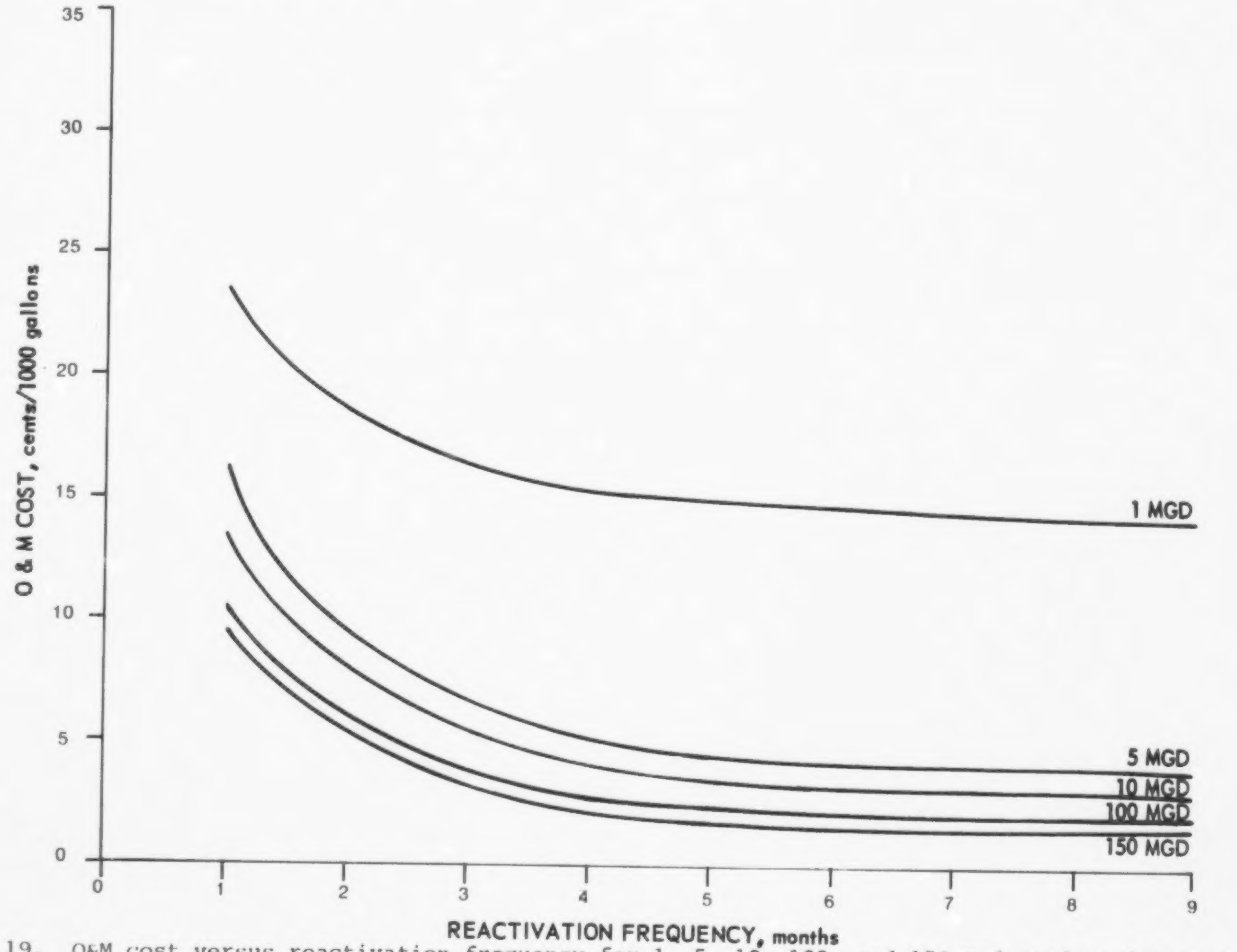

Figure 19. O&M cost versus reactivation frequency for 1, 5, 10, 100, and 150 mgd sand replacement system.

insensitive to power cost and Producers Price Index. Power cost has a greater impact on smaller systems than do some of the other variables.

Capital Cost Effects--

Plant capacity, amortization period, Construction Cost Index, and interest rate have a significant impact on system cost. System costs are relatively insensitive to activated carbon cost. Capital costs are moderately sensitive to reactivation frequency.

SUMMARY AND CONCLUSIONS

Extensive development of curves for various unit processes involved in GAC operations was done in a previous report (Culp/Wesner/Culp, 1979). These curves are designed to be flexible in application and easily updated. Based on these data, an analysis of the cost of GAC used in water supply has been completed. The sensitivity of GAC system costs to changes in certain operating variables has been examined. Several variables have been identified as important. These include choice of system configuration, loading rate and size of system, reactivation frequency, interest rate and life of system, local construction and operating costs, inflation, and carbon use rate.

SECTION 7

REPORT SUMMARY

On January 9, 1978, the U.S. Environmental Protection Agency (EPA) proposed the use of Granular Activated Carbon (GAC) as a means of treating drinking water. Since that time much has been written both for and against using GAC in this manner. Serious challenges and many questions have been raised regarding EPA's cost estimates for GAC use. To respond to some of these questions, EPA's Drinking Water Research Division initiated a carefully designed study to establish water supply unit process cost curves on a consistent and understandable basis.

A study performed by Culp/Wesner/Culp under EPA Contract No. 68-03-2516, focused on processes capable of removing those contaminants included in the National Interim Primary Drinking Water Regulations and developed construction and operation and maintenance cost curves for these processes. Its final report for this project contains cost curves for 99 different unit processes. These cost curves were divided into categories: large water treatment systems applicable to flows between 1 and 200 mgd and small water treatment systems applicable to flows between 2,500 gpd and 1 mgd. A computer program for retrieving, updating, and combining the cost data was also developed. This present report addresses that portion of the study related to cost curves associated with GAC applications. It also extends the cost study by presenting 22 case histories of operating municipal and industrial GAC installations for treating water and wastewater and for processing food and beverage products.

CONCLUSIONS

Some conclusions resulting from the inspection of 22 operating GAC absorption and reactivation systems and a study of the costs involved are:

1. A substantial number of GAC installations have been operating successfully for many years. These installations include facilities for treating water and wastewater and for processing food and drink.

2. Although there has been widespread, long-term use of GAC and powdered activated carbon (PAC) by municipal waterworks and industries, no adverse health effects have been reported.

3. GAC treatment of public water supplies to remove trace organics is fairly new. Only limited direct design data or cost information are available.

4. GAC treatment of public water supplies for taste and odor control or color removal is practiced in about 46 cities in the United States. In

this application of GAC, however, there is little need for reactivation and little experience with on-site reactivation.

5. EPA is presently sponsoring five reactivation studies that will soon yield good GAC performance and cost data for water supply installations.

6. Twenty to thirty GAC installations in food (corn syrup and beet sugar) processing plants give insight concerning the safety of GAC but add little to the available cost data. Some design ideas and information can be obtained from these sources.

7. Twenty to thirty GAC reactivation furnaces in industrial water pollution control plants yield some information on operation and cost of GAC systems.

8. The best sources of detailed cost information and equipment design data are the 20 or so operating municipal advanced waste treatment (AWT) plants using GAC.

9. Pilot plant testing of GAC adsorptive and reactivation characteristics in municipal water treatment plants can be combined properly with the known costs of GAC systems in wastewater treatment to yield a design basis and preliminary cost estimates that are satisfactory for developing water treatment projects. Designers should take full advantage of applicable GAC use and experience available from:

   - municipal water treatment for taste and odor control,
   - municipal AWT,
   - industrial wastewater treatment, and
   - food and pharmaceutical production.

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APPENDIX

CASE HISTORIES OF MUNICIPAL AND INDUSTRIAL GRANULAR ACTIVATED CARBON INSTALLATIONS IN THE UNITED STATES

CASE HISTORY NO. 1
SOUTH TAHOE (CALIFORNIA) PUBLIC UTILITY DISTRICT
MUNICIPAL WASTEWATER TREATMENT

HISTORY AND INTRODUCTION

The South Tahoe wastewater reclamation plant was the first full-scale municipal wastewater treatment plant in the United States to use GAC, and therefore, it has the longest record of performance to draw upon. During 14 years of GAC treatment, the character of the wastewater to be treated and the standards to be met have changed so that operational data are available for more than one set of conditions. To supplement the routine data collection efforts, a special EPA funded 3-year study made it possible to collect and analyze much more complete and detailed data on plant performance and operational costs than would be possible under normal circumstances.

In 1963, the South Tahoe plant was designed without the benefit of any information from full-scale municipal wastewater treatment GAC operations, because there was none at the time. Rather, the design was based on: (1) the knowledge and experience gained by industries in decolorizing sugar and refining corn syrup with GAC; (2) laboratory and pilot plant work done by EPA researchers at Cincinnati; and (3) information from GAC suppliers and carbon reactivation furnace manufacturers, all as modified by applying the results of laboratory experiments (carbon isotherms and muffle-furnace reactivation) and pilot plant operations (at 1 and 25 gpm rates) at South Tahoe.

This transfer and modification of data from an indirectly related field (food processing) to wastewater treatment, as modified by pilot plant experience, is somewhat parallel to the transfer of data that is now being attempted from wastewater treatment to drinking water purification. Actually, these present relationships are probably closer than these earlier ones. The transition from food processing to wastewater treatment was successful. Therefore, it is logical to expect that the lessons learned and the knowledge gained in wastewater treatment with GAC may be applied even more directly and more accurately to water purification than was done in the previous transition. Indeed, by using accumulated experience in wastewater treatment as properly modified by pilot plant tests of water purification, it should be possible to design, construct, and operate GAC systems to improve drinking water quality without risk of major overdesign or underdesign. Also, capital and O&M (operation and maintenance costs) should be predictable within a reasonable degree of accuracy.

DESIGN DATA

Originally, the GAC facilities at South Tahoe were designed for a maximum daily flow of 2.5 mgd. This plant was operated from 1966 until 1968, when plant capacity was expanded to a maximum daily flow of 7.5 mgd. Because no major changes in the basis of GAC system design, other than the capacity increase were made in the plant expansion, the design data are presented for the 7.5 mgd plant.

It is important to note that the design is based on maximum daily flow (in accordance with water works practice) rather than on average dry weather flow (wastewater treatment practice). This was done because of the strict effluent quality standards that applied under maximum flow conditions,--standards that, at the time, were out of the ordinary for wastewater treatment. In a year during which the maximum daily flow is 7.5 mgd, the corresponding average daily dry weather flow is 5 mgd.

Basic of GAC System Design

Flow	Maximum daily, 7.5 mgd Peak hourly flows are equalized by in-plant storage before GAC treatment
COD	
Raw wastewater, average	280 mg/L
Carbon column influent, average	35 mg/L
Carbon column effluent, average	20 mg/L
GAC contact time, minimum	17 min
Granular activated carbon mesh	Calgon Filtrasorb; coal base; 8 x 30
Makup carbon unloading	Bag dump (manual) Bulk - hydraulic eductor
Carbon contactors (see typical section Figure A-1)	
Type	Upflow packed bed; countercurrent
Number	Eight; 12-ft diameter by 12-ft straight sidewall steel shell; coal-tar epoxy coated inside; 45° conical top and bottom; 14.5-ft carbon bed depth
Inlet	Eight; 12-in. diameter x 2.5-ft long Johnson well screens; 304 SS; 100 psi; 0.020-in. slot opening; closed bail bottom
Outlet	Same as inlet
Column	Equipped with screened vent--combination pressure air and air-vacuum release valve

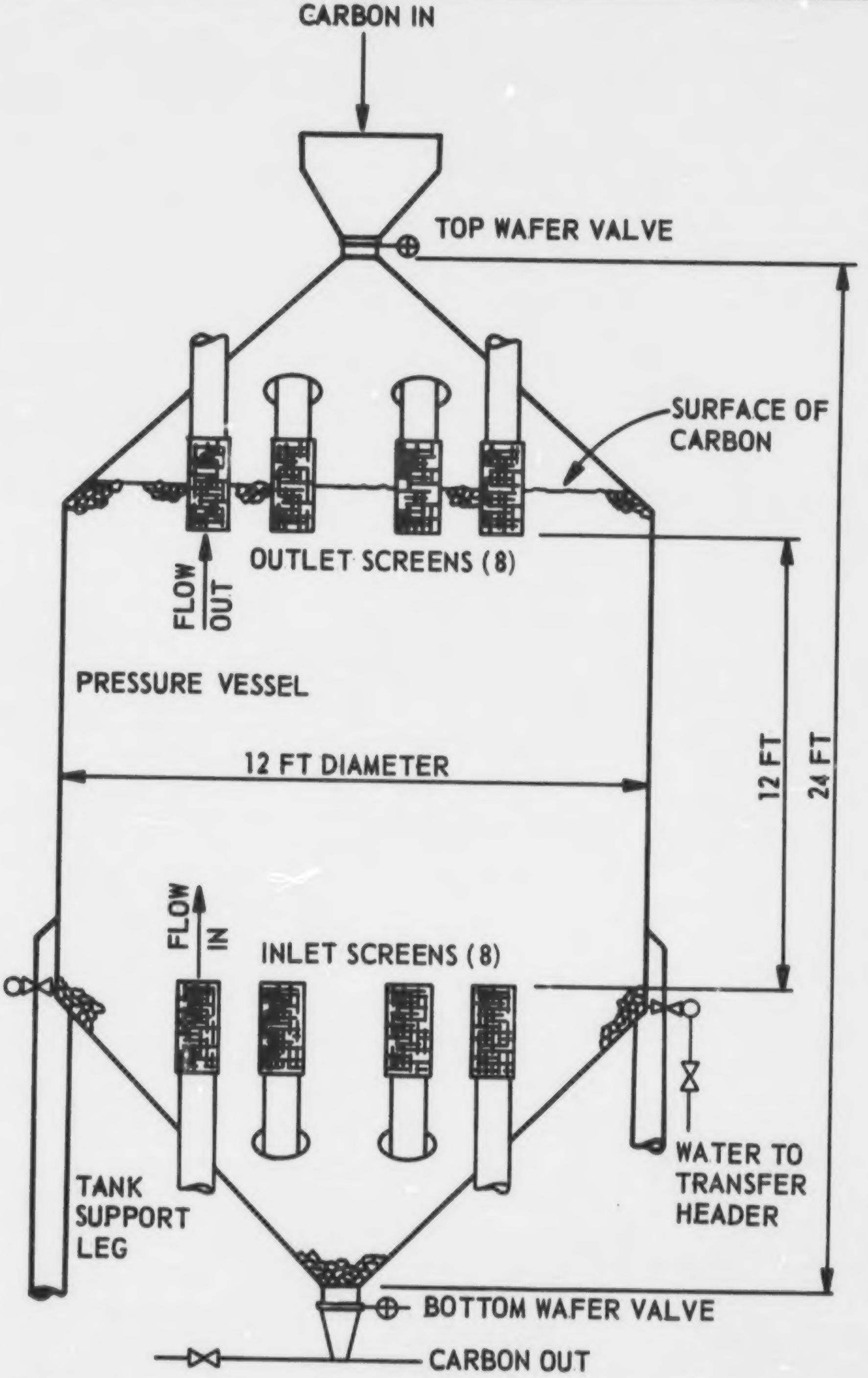

CARBON IN
TOP WAFER VALVE
SURFACE OF CARBON
OUTLET SCREENS (8)
FLOW OUT
PRESSURE VESSEL
12 FT DIAMETER
12 FT
24 FT
FLOW IN
INLET SCREENS (8)
TANK SUPPORT LEG
WATER TO TRANSFER HEADER
BOTTOM WAFER VALVE
CARBON OUT

Figure A-1. Section thru carbon column, South Tahoe Public Utility District, CA.

Rate-of-flow control	Dahl tube and butterfly valve on effluent header
Backwash	Flow can be reverse cleaned
Adding/removing	Carbon can be added and removed while column is in operation
Carbon slurry transfer piping	Black steel; fittings extra heavy; standard radius elbows and tees
Carbon wash tanks	For carbon fines removal from reactivated and makeup carbon; two pressure tanks with Johnson-screened outlets; equipped for flow reversal to clean screens; each tank holds 5% of one carbon column volume; wash tanks also serve as blowcases (hydraulic) for carbon transfer

GAC reactivation (see schematic, Figure A-2)

Number	One; 54-in. diameter by six-hearth BSP--Envirotech gas-fired furnace with propane standby
Rated capacity	6,000 lb/day
Odor/particulate control	Equipped with afterburner for odor control (ordinarily not used); exhaust gas scrubber for removal of particulates
Spent carbon dewatering tanks	Two; to 40% moisture in 10 min when screen drains are clean; each tank holds 5% of volume of one carbon column
Carbon feed to furnace	Two inclined 304 SS screw conveyors with variable speed (10:1) drive
Quench tank location	Single reactivated carbon quench tank directly below furnace outlet and above two diaphragm slurry pumps that discharge to carbon wash tanks

CARBON SYSTEM OPERATION

Carbon Adsorption System

The eight carbon columns are operated in parallel, with the flow traveling upward from top to bottom. The flow can be reversed to flush the top screens, compact the carbon bed, or remove the carbon in the lower portion of the column. This backwashing is usually done when the headloss across the column reaches 12 ft of water. The regenerated carbon is added to the top of the column.

Flow through each column is maintained at greater than 500 gpm to ensure proper performance. Studies showed that at flows less than this value, mud balls and odors became operational problems. Carbon losses from the tanks were small--about 20 ft^3 per column between regeneration periods.

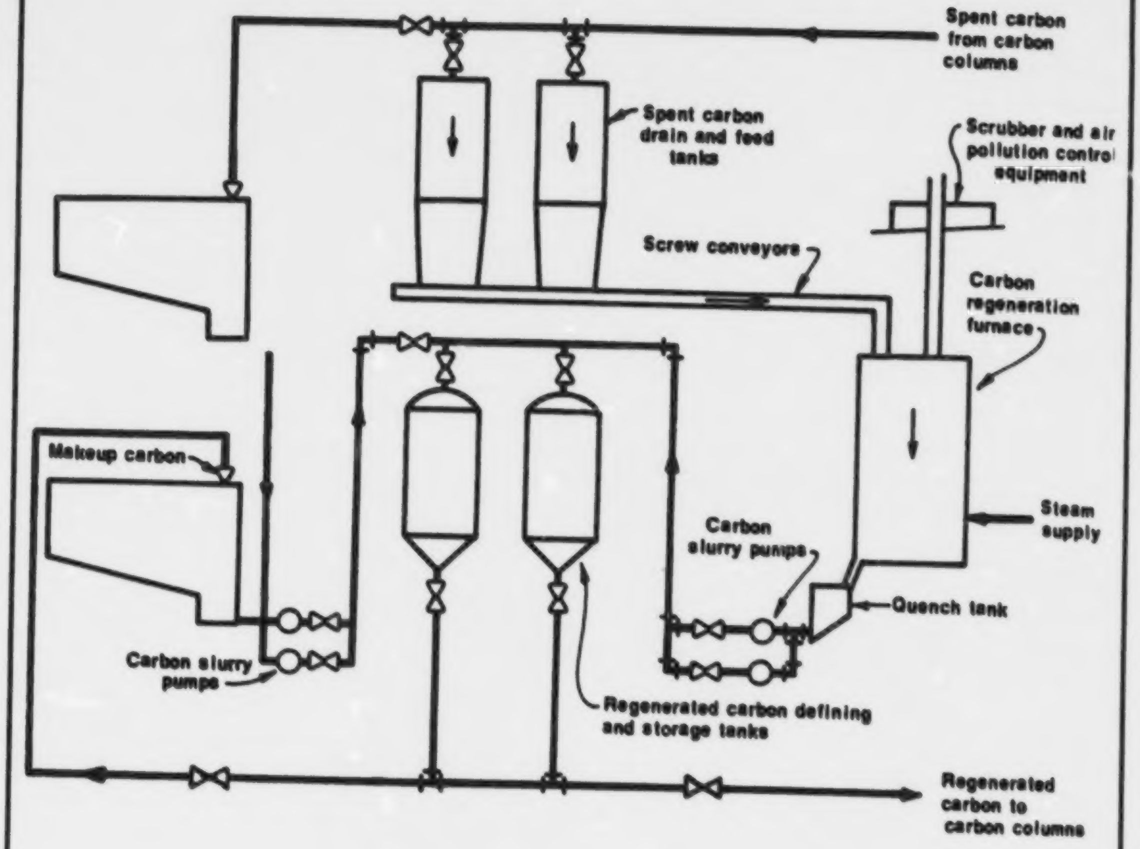

Spent carbon from carbon columns
Spent carbon drain and feed tanks
Scrubber and air pollution control equipment
Screw conveyors
Carbon regeneration furnace
Makeup carbon
Steam supply
Carbon slurry pumps
Quench tank
Carbon slurry pumps
Regenerated carbon defining and storage tanks
Regenerated carbon to carbon columns

Figure A-2. Carbon regeneration system, South Tahoe Public Utility District, CA.

Carbon Reactivation

Spent carbon is withdrawn from each column and transferred to a dewatering bin. From there it is fed to a 6-hearth furnace for reactivation. Reactivation is done at a temperature of 1650° to 1750°F in an oxygen-limited atmosphere. Organic impurities are volatized, and the reactivated carbon is cooled and de-fined before being reused. During the initial startup and intensive testing periods, an attempt was made to return the reactivated carbon to the column from which it came. Virgin carbon was added to the columns as needed to make up for reactivation losses.

Major GAC System Repairs

Carbon reactivation equipment and carbon slurry conveying facilities are subject to rather severe service conditions. The 14 years of experience at South Tahoe indicates the nature and cost of major repairs that may be expected in addition to routine maintenance (Table A-1).

TABLE A-1. MAJOR CHANGES AND REPAIRS, SOUTH TAHOE GAC SYSTEM

Year	Description	Maintenance labor, hr	Materials & supervision, cost
1973	Rebuild furnace burners	480	$ 3,000
1976	Rebuild reactivation furnace	1,440	8,000
1977	Repair top hearth	480	2,000
1978	Add new facilities for bulk handling of GAC	160	8,000
1979	Rebuild exhaust gas system, repair screw conveyor		72,000
1973-1979	Replace 128 50 psi carbon column screens with 100 psi screens	6,144	90,880

In addition, plant maintenance crews are presently spending about 20 man-hours per week replacing 10 to 14 year old carbon slurry lines on a systematic basis; the aim is to replace all original lines. In the past (1965 to 1979), about 3 hours per week was needed to maintain and repair carbon transfer lines.

Plant maintenance crews estimate the current GAC reactivation furnace downtime for service, adjustment, and repair is only about 5 percent of the time (1 1/2 days per month).

CARBON SYSTEM PERFORMANCE

From 1965 through March 1979, during the 14 years of GAC system operation at South Tahoe, all plant flows (a total of 14.5 bil gal of wastewater) have been carbon treated. In evaluating the performance of the GAC system, three time periods are significant because of three different sets of operating conditions that prevailed.

- 1965-1974 - Initial period when design COD loading conformed to pilot plant conditions, plant operation was normal, and data collection was at a peak.
- 1974-1977 - Unusual operating conditions due to 80 percent increase in design COD; carbon use increased to maintain discharge requirement; high carbon use because spent carbon overburned during reactivation.
- 1978-1979 - Return to normal operation as a result of relaxed COD standard; high influent COD loading prevailed.

The first and third periods of plant performance represent excellent and good conformance to discharge requirements, whereas the second period was one during which COD requirements were slightly exceeded intermittently.

Detailed Performance Data

The information concerning plant operations for 1968-1970 is typical for the initial period of plant operations from 1965-1974. The GAC system operated up to the full expectations developed in the pilot plant tests. Discharge requirements met fully and continuously from the system's first application in 1968 through 1974--a period of about 7 years. All GAC was reactivated on-site with virtually no decrease in adsorption of wastewater organics despite a slight drop in iodine number and other indirect indicators of carbon capacity. The performance data from 1968 to 1971 are summarized from "Advanced Wastewater Treatment as Practiced at South Tahoe."[21]

Between November 1968 and January 1971, the carbon column flow was 3,341 mg and 23,050 ft^3 or 691,000 lb of activated carbon were regenerated; this provided a carbon dosage rate of about 207 lb regenerated carbon/ mil gal carbon column flow (Table A-2). For the same period, an average of 0.8 lb of COD were removed per lb of carbon. An average of 0.027 lb of MBAS was applied per lb of regenerated carbon, and 0.021 lb of MBAS was removed per lb of carbon.

The average furnace feed rate for the batch regeneration periods was 176 lb/hr, or about 6 ft^3/hr. Fuel requirements per lb of carbon averaged 2,900 Btu at 860 Btu/ft^3 of natural gas at 18 to 20 psia. Numbers four and six furnace hearth temperatures averaged 1650° and 1760°F, respectively. Carbon losses in the furnace and in transport to and from the furnace averaged 8 percent that period. In the batch regeneration used at Tahoe, it took approximately 1 year for an entire column to pass through one generation cycle.

TABLE A-2. AVERAGE CARBON EFFICIENCY FOR THE REGENERATION PERIOD NOVEMBER 1968 THROUGH JANUARY 1971

Parameter/unit	Average	Maximum	Minimum
Carbon dosage (lb reg/mg treated)*	207	418	111
Iodine number†			
Spent carbon	583	633	497
Regenerated carbon	802	852	743
Apparent density (g/cc)			
Spent carbon	0.571	0.618	0.544
Regenerated carbon	0.487	0.491	0.478
Percent ash†			
Spent carbon	6.4	7.0	5.8
Regenerated carbon	6.8	7.2	5.8
Chemical oxygen demand			
Percent removal	49.9	63.3	30.1
lb COD applied	28,250	54,970	15,680
lb COD applied/mil gal	162	254	105
lb COD removed/mil gal	81	149	32
lb COD applied/lb carbon regenerated*	0.78	1.56	0.52
lb COD removed/lb carbon regenerated*	0.39	0.71	0.16
Methylene blue active substances (MBAS)			
Percent removal	77.0	93.0	58.0
lb MBAS applied	995	1,675	457
lb MBAS applied/mil gal	5.7	10.7	2.6
lb MBAS removed/mil gal	4.4	8.2	1.6
lb MBAS applied/lb carbon regenerated*	0.027	0.045	0.012
lb MBAS removed/lb carbon regenerated*	0.021	0.039	0.007

*Based on ft^3 of carbon fed to furnace at 30 lb/ft^3.
†November 1968 through November 1970.

The virgin carbon, from the 1965 and 1968 purchases, had an average iodine number of 935, an apparent density of 0.485 g/cc, and an ash content of 5.0 percent. The spent carbon before regeneration had an average iodine number of 583, an apparent density of 0.571 g/cc, and an ash content of 6.4 percent. The regenerated carbon had an average iodine number of 802, an apparent density of 0.487 g/cc, and ash content of 6.8 percent. The performance of virgin and regenerated carbon in removing MBAS is illustrated by the isotherms shown in Figure A-3. There is little difference in the performance of MBAS removal, related to the number of regeneration cycles. The same is true for COD removal, except for the considerable difference in performance between the virgin carbon and the first regeneration; after that, the performance is quite consistent.

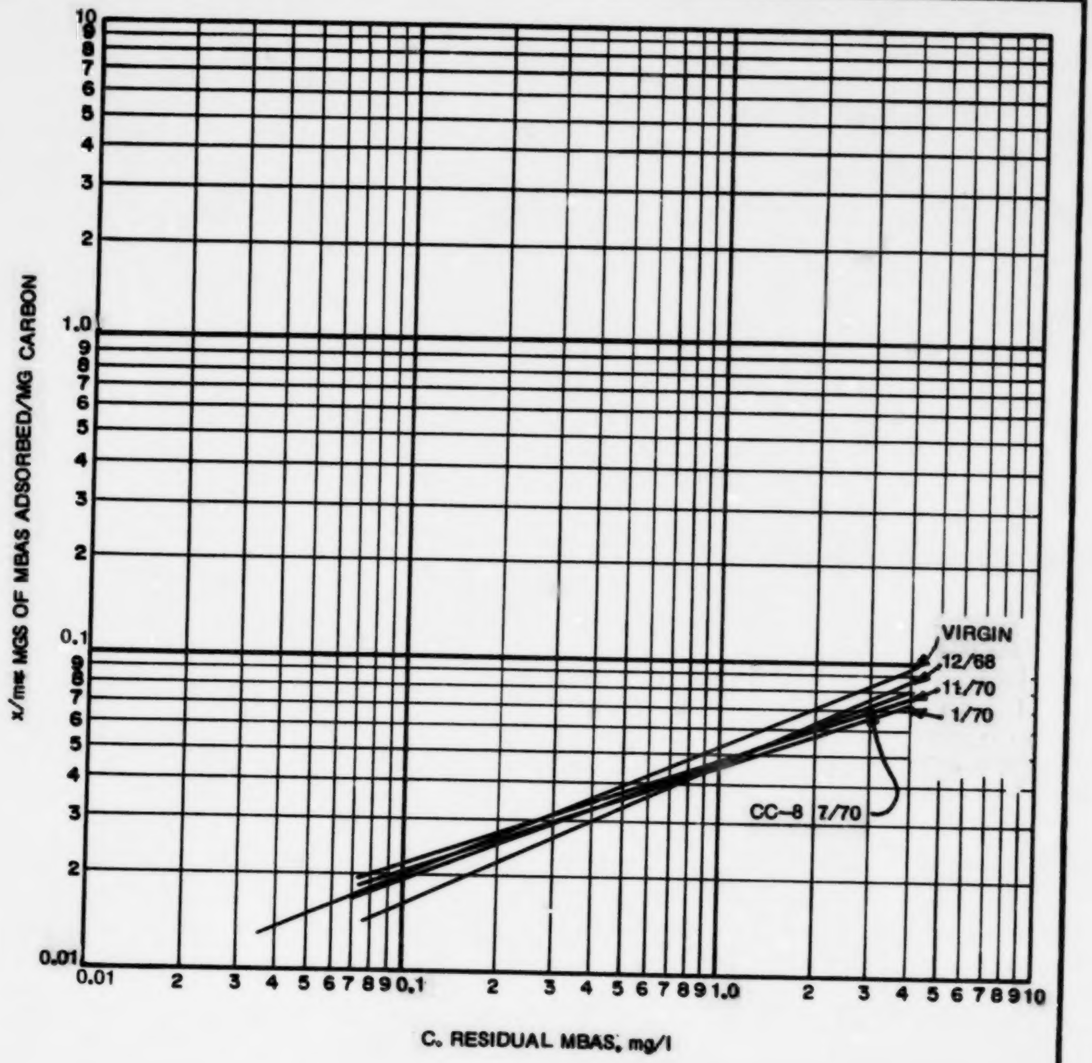
When the influent COD to the South Tahoe plant suddenly increased from 280 to 500 mg/L in 1976, the GAC columns were stressed far beyond their original design conditions. The influent COD to the columns jumped from 20 mg/L to 45 mg/L. To meet discharge requirements of 20 mg/L, the carbon dosage was increased from 210 lb/mil gal of flow treated to 320 lb/mil gal. At the same time, the removal of COD dropped from 0.39 to 0.31 lb/lb carbon reactivated. On occasion, the discharge requirements were violated and operating costs skyrocketed. A study of the situation left two alternatives--either doubling the number of carbon columns or relaxing the discharge requirements. The latter option was exercised after an extensive study concluded that no ill effects would result from an effluent COD limitation of 30 mg/L. Recent operations data show that this concentration can be easily met.

CAPITAL AND OPERATION AND MAINTENANCE COSTS

The most detailed and accurate cost data collected at South Tahoe resulted from the 1968-1970 EPA Demonstration Grant study.

Capital Costs

The capital costs shown in Table A-3 include all equipment and construction costs, but not engineering. Since construction took place over many years and under several contracts, these costs have been adjusted to 1969 using an EPA Sewage Treatment Plant Constructon Cost Index of 127.1.



VIRGIN AND THREE REGENERATION CYCLES
OF CC-5 (DECEMBER 1968, JANUARY 1970, AND NOVEMBER 1970)
AND FOURTH CYCLE OF CC-8 (JULY 1970)

Figure A-3. Isotherms for regenerated carbon.

TABLE A-3. SOUTH TAHOE PUBLIC UTILITY DISTRICT, CALIFORNIA, CAPITAL COSTS FOR CONVENTIONAL AND ADVANCED WASTE TREATMENT PLANT, 7.5 MGD DESIGN CAPACITY

Treatment phase	Actual contract total const. cost per phase*	Estimated national average replacement const. cost for 1969	Estimated replacement costs per mg for 1969
Carbon treatment			
Carbon adsorption†	$656,000	$632,000	$16.30
Carbon regeneration	193,000	199,000	5.20
Subtotal, carbon treatment	849,000	831,000	21.50

*Construction costs are taken from District records of actual contracts awarded for various phases. Contracts for construction were completed at various periods between 1960 and 1968. These costs have not been adjusted to a common year.

†Includes initial carbon costs to fill all carbon columns.

Operation and Maintenance

The operating costs are based on the plant design capacity of 7.5 mgd from February 1969 to December 1970. During this period, the actual average monthly influent flows varied between 1.79 mgd and 3.15 mgd. As a result of recycling the water from scrubber flows, backwashing filters, and backflowing carbon columns, the filtration and carbon adsorpton flows during the same period varied between 3.13 mgd and 5.22 mgd.

To compare operating costs on the common basis of the plant design capacity, it was assumed the total cost for fuel, chemicals, make-up lime, and make-up carbon would increase in proportion to the flow. The same assumption, however, could not be made for electricity, O&M labor costs, equipment repair, and instrument maintenance. Costs per day for electricity were adjusted upward to reflect the equipment characteristics at 7.5 mgd. The cost per day for O&M labor, repair materials, and instrument maintenance were assumed to be the same as present design flows.

Table A-4 summarizes the cost of operating the GAC units to treat 7.5 mgd in 1970. The unit costs for labor, energy, and make-up carbon are given in Table A-5.

TABLE A-4. OPERATING AND UNIT CAPITAL COSTS FOR SOUTH TAHOE GAC COLUMNS AND REACTIVATION SYSTEM (1970 DOLLARS)

Operating cost	GAC treatment $/day	GAC reactivation $/day	Total $/day
Electricity	$47.34	$ 2.23	$ 49.57
Natural gas	-	6.15	6.15
Make-up carbon	-	70.39	70.39
Operating labor	24.53	91.90	116.43
Maintenance labor	3.27	16.21	19.48
Repair material	1.15	1.17	2.32
Instrument maintenance	4.24	1.90	6.14
Total operating cost	$80.53	$189.95	$220.48
Total cost	**$/mil gal**	**$/mil gal**	**$/mil gal**
Operating	$10.74*	$ 25.33	$ 36.07
Capital†	16.30	5.20	21.50
Total	$27.04	$ 30.53	$ 57.57

*Total operating cost per million gallons of water treated would be 8.77/mil gal. This figure includes 7.5 mgd plant influent, plus recycle streams.

†Includes initial carbon charge.

TABLE A-5. UNIT COSTS* 1969 AND 1970, AND 1979

	1969/1970	1979
Labor†		
Operations	$ 6.11/hr	$10.30/hr
Maintenance	5.05/hr	
Electricity**	12.10/1000 kwh	44.00/1000 kwh
Fuel§	0.0543/therm	2.52/1000 ft^3
Activated carbon makeup¶	0.305/lb	0.66/lb
Off-site carbon reactivation	-	0.45/lb

*All appropriate unit costs are f.o.b. South Lake Tahoe and include a 5% California sales tax.

†Labor costs include all direct and indirect monies paid upon the employees behalf. The rates are averages for 1969 and 1970.

**Includes energy and demand charges.

§Natural gas at about 860 Btu ft^3 at 6,200 ft elevation and billed on the basis of interruptable service.

¶Activated carbon at 30 lb/ft^3.

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CASE HISTORY NO. 2
TAHOE-TRUCKEE SANITATION AGENCY
MUNICIPAL WASTEWATER TREATMENT

HISTORY AND INTRODUCTION

The Tahoe-Truckee Sanitation Agency (TTSA) was formed on May 1, 1972, to carry out the mandate of the Porter Cologne Water Quality Control Act, a California law requiring the exportation of all sewage from the Lake Tahoe Basin. The newly formed Agency's initial task was to consider the design and construction of a regional wastewater treatment facility that would replace existing interim facilities operated by its member entities (the Tahoe City Public Utility District, the North Tahoe Public Utility District (both located in the Lake Tahoe drainage basin), the Alpine Springs County Water District, the Squaw Valley County Water District, and the Truckee Sanitary District), which are located in the Truckee River drainage basin. The Agency is governed by a Board of Directors composed of five appointed directors, one from each member district.

It was decided that retaining the effluent in the Truckee River Basin was of primary importance so that the quantity of water available to downstream users would not be diminished by this project; that treating the wastewater to a high degree at a plant near Truckee was the most economical with the least adverse impact on the environment; and that adhering to the existing high water quality standards required of the Truckee River could not be done by simply upgrading the existing plants. The State of California's rigid waste discharge requirements necessitated the implementation of the most highly sophisticated treatment available.

The project, which was finally selected from many alternatives studied, required constructing an interceptor line from Tahoe City to Truckee, California; constructing a 4.83 mgd advanced waste treatment plant in Martis Valley near Truckee, California; and installing an underground effluent disposal system at a total cost of $32 million. Full tertiary treatment, including maximum removals of nitrogen and phosphorus and granular activated carbon adsorption, was deemed necessary to protect the quality of the Truckee River, into which the effluent would ultimately find its way after percolation into the permeable glacial outwash soil near the plant. This would ensure the safety and integrity of this primary water source for Reno, Nevada, 30 miles downstream.

Studies of the background concentration of pollutants in the Truckee River revealed that the critical pollutants were total nitrogen and total phosphorus. These were also the most difficult contaminants to remove; other pollutants could easily be removed. The primary goal of process design was to ensure that the treated effluent, when mixed with background concentrations existing in the river, would not violate the river standards even if discharged directly into the river. Percolation into the Martis Valley soils (where a residence time of about 150 days would be experienced) would provide an additional treatment factor. The effluent's mixing with natural groundwater moving through the soil would provide additional dilution of any residual pollutants.

Briefly, the major sewage treatment processes employed are: primary clarification; pure oxygen activated sludge; lime treatment and chemical clarification for phosphorus removal; two-stage recarbonation with intermediate calcium carbonate settling; flow equalization, mixed media filtration; granular activated carbon adsorption; ion exchange ammonia removal using clinoptilolite; and disinfection. Sidestream processes include sludge thickening; anaerobic digestion of organic sludges; sludge dewatering using high pressure filtration of chemical and organic sludges; thermal reactivation of activated carbon; and clinoptilolite regenerant recovery using chemical clarification and ammonia stripping. The process flow diagram is presented in Figure A-4.

Sewage originates from the communities on the north and west shores of Lake Tahoe and along the Truckee River Corridor from Lake Tahoe to Truckee, California. The area's major industry, tourism, has two primary seasons; the winter ski season and the summer season. Heavy influx of tourists results in extremes of sewage flows and loadings over holidays, weekends, and seasonal peaks.

Effluent from the plant is indirectly discharged to the pristine receiving waters of the Truckee River and, consequently, the discharge limits (Table A-6) imposed on the Agency by the State Water Resources Control Board are stringent, and necessitate a very high degree of treatment. Compliance with COD requirements depends to a great extent on the performance of the GAC system.

TABLE A-6. TAHOE-TRUCKEE SANITATION AGENCY DISCHARGE REQUIREMENTS

Constituent/unit	10-sample average	Daily maximum
COD, mg/L	15	40
Suspended solids, mg/L	2.0	4.0
Turbidity, NTU	2.0	8.0
Total nitrogen, mg/L	2.0	4.0
Total phosphorus, mg/L	0.15	0.4
MBAS, mg/L	0.15	0.4
Total dissolved solids, mg/L	440	-
Chloride, mg/L	110	-
Total coliform organisms, MPN/100 mL	-	23

DESIGN DATA

GAC Adsorption System

Flow	Maximum daily = 4.83 mgd Peak hourly flows are equalized by in-plant storage before GAC treatment

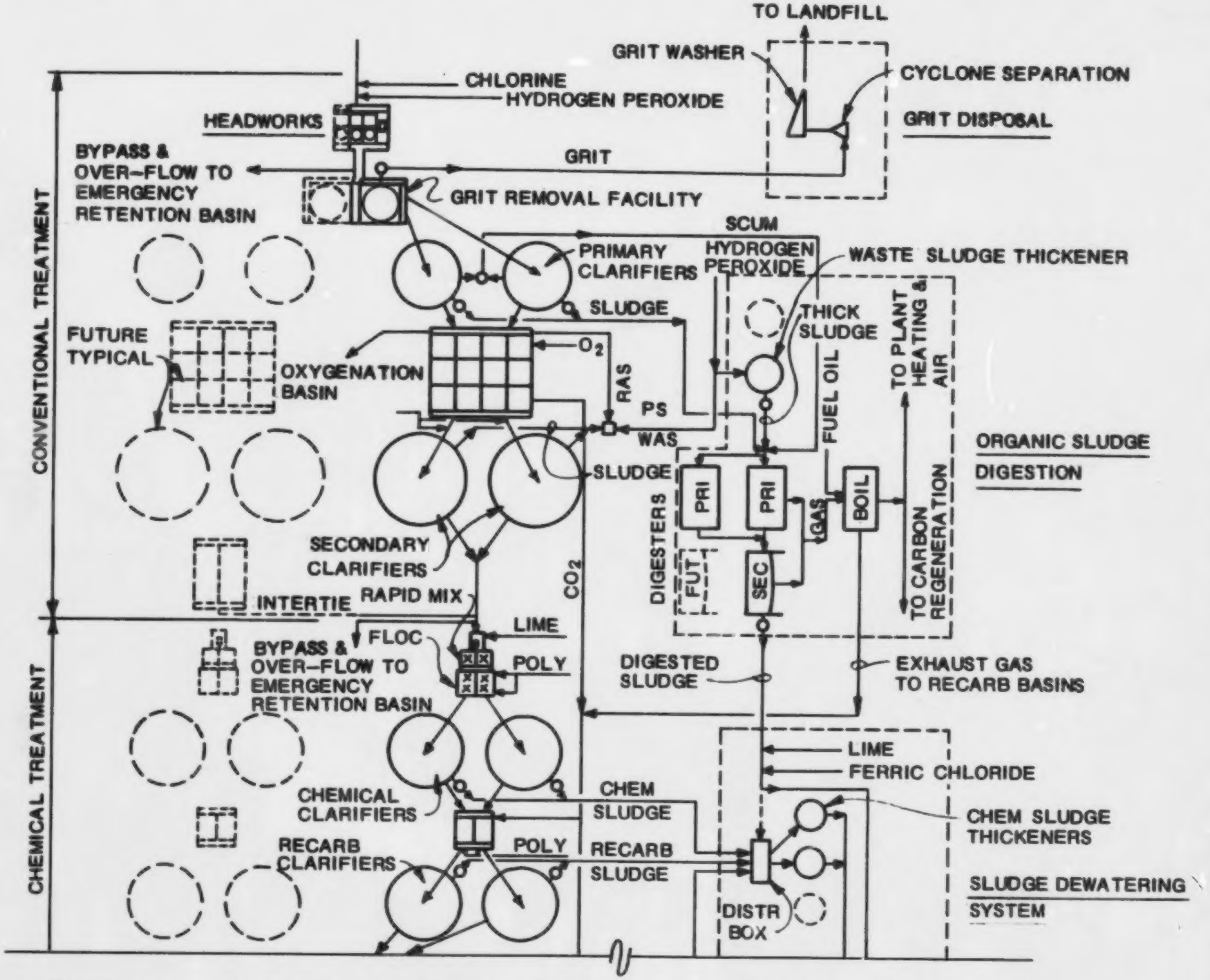
TO LANDFILL
GRIT WASHER
CYCLONE SEPARATION
GRIT DISPOSAL
CHLORINE
HYDROGEN PEROXIDE
HEADWORKS
BYPASS & OVER-FLOW TO EMERGENCY RETENTION BASIN
GRIT
GRIT REMOVAL FACILITY
SCUM
HYDROGEN PEROXIDE
PRIMARY CLARIFIERS
WASTE SLUDGE THICKENER
SLUDGE
THICK SLUDGE
FUTURE TYPICAL
OXYGENATION BASIN
O_2
RAS
PS
WAS
FUEL OIL
TO PLANT HEATING & AIR
SLUDGE
ORGANIC SLUDGE DIGESTION
PRI
PRI
GAS
BOIL
DIGESTERS
FUT
SEC
TO CARBON REGENERATION
CONVENTIONAL TREATMENT
SECONDARY CLARIFIERS
CO_2
INTERTIE
RAPID MIX
LIME
FLOC
POLY
BYPASS & OVER-FLOW TO EMERGENCY RETENTION BASIN
DIGESTED SLUDGE
EXHAUST GAS TO RECARB BASINS
LIME
FERRIC CHLORIDE
CHEMICAL TREATMENT
CHEMICAL CLARIFIERS
CHEM SLUDGE
CHEM SLUDGE THICKENERS
RECARB CLARIFIERS
POLY
RECARB SLUDGE
SLUDGE DEWATERING SYSTEM
DISTR BOX

Figure A-4. Plant process diagram, Tahoe-Truckee Sanitation Agency, CA.

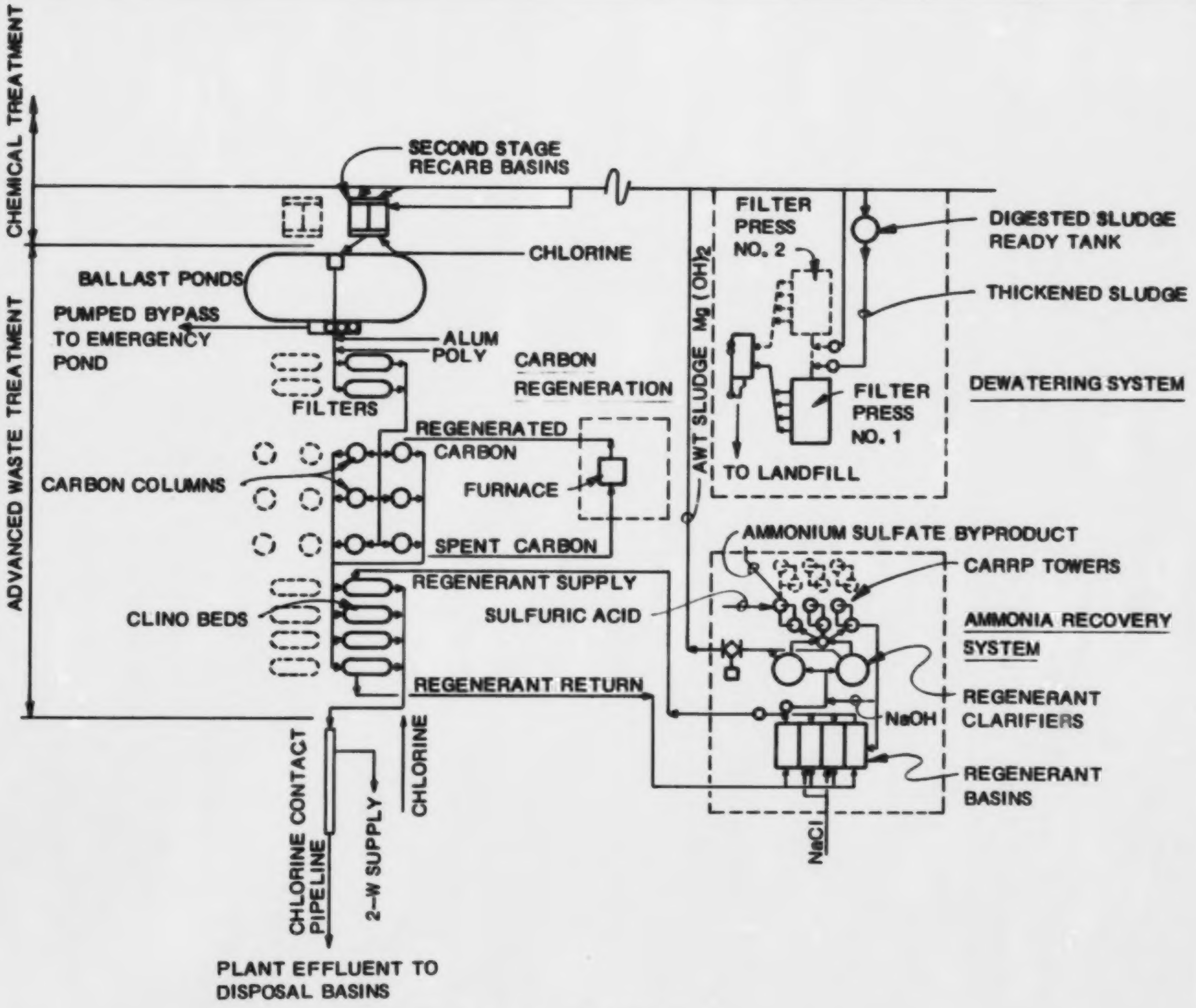
CHEMICAL TREATMENT
ADVANCED WASTE TREATMENT
SECOND STAGE RECARB BASINS
CHLORINE
BALLAST PONDS
PUMPED BYPASS TO EMERGENCY POND
ALUM
POLY
FILTERS
CARBON REGENERATION
REGENERATED CARBON
CARBON COLUMNS
FURNACE
SPENT CARBON
REGENERANT SUPPLY
CLINO BEDS
SULFURIC ACID
REGENERANT RETURN
CHLORINE CONTACT PIPELINE
2-W SUPPLY
CHLORINE
PLANT EFFLUENT TO DISPOSAL BASINS
FILTER PRESS NO. 2
AWT SLUDGE Mg (OH)2
TO LANDFILL
FILTER PRESS NO. 1
DIGESTED SLUDGE READY TANK
THICKENED SLUDGE
DEWATERING SYSTEM
AMMONIUM SULFATE BYPRODUCT
CARRP TOWERS
AMMONIA RECOVERY SYSTEM
REGENERANT CLARIFIERS
NaOH
REGENERANT BASINS
NaCl

Figure A-4. (Continued)

COD	
Raw wastewater, average	400 mg/L
Carbon column influent, average	26 mg/L
Carbon column effluent	15 mg/L
10-sample average, maximum	40 mg/L
GAC contact time, minimum	20 minutes
Granular activated carbon	400,000 lb; Westvaco; coal base; 8 x 30 mesh; suitable for 20 cycles of reuse after thermal reactivation; less than 10% of total loss per cycle; COD to be reduced from 20 mg/L to 10 mg/L at detention time of 20 min; carbon shall attain max COD loading of 0.333 lb COD/lb carbon under these conditions
Makeup carbon unloading	Bag dump, manual with hydraulic eductor
Carbon contractors	
Type	Upflow packed bed; countercurrent
Number	Six
Size	Vertical, cylindrical 12-ft diameter by 20-ft straight sidewall steel shell; 90 psi working pressure; coal-tar epoxy coated inside; 45° conical top and bottom; 20-ft carbon bed depth
Inlet	Eight; 12-in. diameter x 2.5-ft long Johnson well screens; 304 SS; 100 psi; 0.020-in. slot opening; closed bail bottom
Outlet	Same as inlet except screen slot size is 0.015 in.
Column	Equipped with screened vent--combination pressure air and air-vacuum release valve
Rate-of-flow control	Propeller meter and butterfly valve
Backwash	Flow can be reversed for cleaning at a rate of 15 gpm/sf
Carbon slurry transfer piping	Black steel; fittings extra heavy standard radius elbows and tees

GAC Reactivation System

The carbon reactivation system includes facilities for the following:

- de-fining and transferring makeup carbon to the carbon columns,
- receiving and dewatering spent carbon,
- feeding spent carbon at a controlled rate to the furnace and thermally reactivating spent carbon,
- quenching the carbon and conveying the reactivated carbon to de-fining and transfer tanks,
- de-fining and transferring reactivated carbon to the carbon columns and carbon storage tank,
- scrubbing and cooling all exhaust gases,
- storing spent, reactivated, or makeup carbon in the carbon storage tank.

The major equipment items installed for the carbon reactivation system include the following:

- two dewatering bins and conveyors,
- two carbon feeders,
- carbon reactivation furnace exhaust gas cooling and scrubbing equipment,
- quench tank,
- two transfer and defining tanks,
- one storage tank, and
- virgin carbon hydraulic eductor and dust collector.

The reactivation furnace has the following design characteristics:

Number/type	One; 81-in. diameter by six-hearth BSP - Envirotech propane fired furnace with fuel oil standby
Rated capacity	3,840 lb/day of carbon plus 1,980 lb/day of adsorbate
Odor and particulate control	Afterburner for odor control; exhaust gas scrubber for removal of particulates
Hearth loading	Less than 45 lb/day reactivated carbon per ft^2 of hearth
Fuel consumption	Less than 22,000,000 Btu/day
Particulate emissions	Less than 0.1 grain/ft^3 of gas at standard conditions
Odor emissions	None objectionable at 50 ft from point of discharge
Steam	Up to 200 lb/hr of steam at 15 psig available for carbon reactivation
Carbon losses through furnace	Less than 5 percent per single pass through furnace

Auxiliaries to the reactivation furnace include:

Transfer and defining tanks	Two; vertical cylindrical; 8-ft diameter, 7-ft 6-in. sidewalls; dome top; 45° conical bottom; carbon steel; epoxy lined; 100 psig working pressure; 304 SS screens with 0.020 in. slots
Virgin carbon feeder	Hydraulic eductor to defining tanks
Dust collector exhaust fan	2,000 scfm at 10-ft of water
Storage tank for carbon	Vertical cylindrical; carbon steel; open top; 45° cone bottom; 12-ft diameter, 15-ft straight sidewall; screened overflow
Dewatering bins	Two; vertical; 7-ft square; 7-ft 6-in. straight sidewalls; open top; hopper bottom; carbon steel; drain screen, 304 SS, 4-in. diameter by 3 ft long with 0.020 slots
Carbon feed to furnace	Two; inclined 304 SS screw conveyors with variable speed (10:1) drive; drain connection at bottom with 304 SS screens with 0.020-in. slots
Combustion air blower	1,000 scfm at 22 ounces
Carbon quench tank	Single reactivated carbon quench tank directly below furnace outlet and above two centrifugal type slurry pumps; capacity 160 lb/hr from 1,800° to 150°F; 1-ft 8-in. diameter by 2-ft 6-in. high, with screened overflow; carbon steel
Quench tank eductors	Two; abrasive-resistant metal; 15 gpm; 1/2 lb carbon/gal water
Precooler	316 SS, with spray assemblies
Scrubber for combustion gases	Three-stage impingement; plate-type vertical unit; pressure drop 9-in. of water; 50 gpm at 30 psig scrubber water
Induced draft fan	Centrifugal type; 800 scfm at 170°F; static pressure of 18-in. water; 304 SS
Dust scrubber	304 SS; 3-in. pressure drop; 30 gpm at 40 psig
Filter	Combustion air intake; dry type; replaceable element; washable.

CARBON SYSTEM PERFORMANCE

Operating the activated carbon adsorption column has been troublefree, and the removal process has consistently worked well in removing COD and MBAS. From May 1, 1979, to November 1, 1979, plant performance for removals of COD, nitrogen, and phosphorus have conformed to waste discharge requirements.

Indications of COD breakthrough were initially attributed to exhausted carbon, and the reactivation procedure has been initiated three times to date. During each reactivation procedure, 20 percent of the carbon in each carbon column was removed, reactivated, and replaced. This was done contrary to the design recommendation of 10 percent carbon withdrawal because of problems in furnace operation during the first two reactivations that extended the reactivation process over long periods. During the third reactivation procedure, 20 percent carbon reactivation was again undertaken because the peak summer tourist season was approaching and because the reactivation process was performing so well. In retrospect, it is now believed that the preliminary indications of COD breakthrough in carbon column operation were the result of high pH water that reduced carbon removal efficiency rather than the result of completely exhausted carbon columns.

The scant data accumulated to date regarding carbon removal efficiency an carbon attrition (Table A-7) may be susceptible to considerable errors because twice as much carbon as recommended was reactivated each cycle and the actual state of exhaustion was unknown before reactivation. The extensive carbon make up during the first reactivation procedure (resulting from unknown losses associated with the de-fining of the original carbon), the bedding of the furnace, and the significant burning of carbon during the initial reactivations detract from the value of preliminary data.

TABLE A-7. ACTIVATED CARBON ADSORPTION, SYSTEM PERFORMANCE

Exhaustion cycle	Average contact time, min	COD Final eff., mg/L	COD Overall removal, mg/L	Carbon usage mg/L	Carbon usage lb/mg	Performance kg COD removed / kg carbon spent
#2	47	11.3	13.2	52	431	0.26
#3	45	13.1	14.0	57	473	0.25

Average COD removals through the carbon columns for the first 6 months of operation are presented in Table A-8. Location of the ion exchange beds with their fine-mesh media following the carbon columns has proven effective in reducing losses of carbon fines. Fines that represent both suspended solids (SS) and COD are continuously washed out of the carbon columns in low concentrations and are washed out in high concentrations during the reactivation transfer procedures.

CAPITAL AND OPERATION AND MAINTENANCE COSTS

Capital Costs

In the Tahoe-Truckee project, bid by contractors in December 1976, the GAC system was bid as a part of the contract for the entire AWT plant, The cost information for the carbon adsorption system and the carbon reactivation system have been taken from the Contractor's bid breakdown, which was used for

TABLE A-8. PLANT PERFORMANCE, (6 month averages)

Process stream	SS, mg/L	COD, mg/L	T.N. mg/L	T.P., mg/L
Raw	156	338	32	10.5
Primary effluent	120	-	34	8.7
Secondary effluent	16	57	28	4.9
Chemical clarifier effluent	17	-	-	0.7
Filter effluent	2.8	26	-	-
Carbon column effluent	2.8	15	25	-
Final effluent	1.3	12	3.7	0.3
Discharge requirement	2.0	15	2.0	0.15
Overall removal, %	99.2	96.4	88.4	97.1

progress payments on the construction work. On this basis, the capital costs are as folows:

Carbon adsorption system (previously described in the text), including the original charge of GAC = $619,000
Carbon reactivation system = $950,000

It should be noted that these capital costs do not include: (1) the cost of buildings to house the equipment; (2) electrical costs; or (3) piping costs for connecting the carbon adsorption system to the processes that precede or follow adsorption. Piping and valves internal to the carbon system are included in the capital cost figures given.

Operation and Maintenance Costs

No O&M cost records for the GAC system are available at this time (July 1979), because it is early in the operations phase of this project. The methods and procedures for breaking-down and accumulating cost records for O&M are still under organization and development.

Recently, to determine the efectiveness of land treatment (which follows AWT) in removing COD, the regulatory agencies have temporarily waived the COD requirement for AWT plant effluent. Therefore, it may be some time before accurate records of O&M costs for the GAC system become available.

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CASE HISTORY NO. 3
UPPER OCCOQUAN SEWAGE AUTHORITY, MANASSAS PARK, VIRGINIA
MUNICIPAL WASTEWATER TREATMENT

HISTORY AND INTRODUCTION

The Occoquan Reservoir is the principal water supply source in northern Virginia, serving over 600,000 people. During the past decade, the increased discharges of conventionally treated sewage caused the water quality of the reservoir to deteriorate. To reverse this trend, the Virginia State Water Control Board adopted a comprehensive policy for waste treatment and water quality management in the Occoquan Watershed. A principal element of this policy requires a highly sophisticated regional AWT plant to replace existing inadequate treatment plants.

The task of meeting this State mandate required that political and jurisdictional boundaries be set aside to provide a regional solution to a regional problem. In response to the mandate, in 1971, the jurisdictions in the Occoquan Basin formed the Upper Occoquan Sewage Authority (UOSA). The member jurisdictions of the Authority include Fairfax County, Prince William County, the City of Manassas, and the City of Manassas Park (Figure A-5).

The initial project of the Authority was construction of a regional water reclamation system to eliminate 11 existing treatment plants and reclaim the wastewater in an AWT plant.

The treatment standards (Table A-9) are among the highest in the country.

TABLE A-9. ADVANCED TREATMENT REQUIRED TO PROTECT THE OCCOQUAN RESERVOIR*

Parameter	Weekly average concentration	Approximate removal rate
BOD_5	1.0 mg/L	>99%
COD	10.0 mg/L	98%
Suspended solids	1.0 or less mg/L	>99%
Unoxidized nitrogen	1.0 mg/L	96%
Total phosphorus	0.1 mg/L	>99%
MBAS	0.1 mg/L	>99%
Turbidity	0.4 JTU	--
Coliform bacteria	>2/100 mL	>99%

*The effluent limitations established by the State Water Control Board of the Commonwealth of Virginia are among the most stringent in the country. The plant effluent discharged to Bull Run, a tributary to Occoquan Reservoir, must be within the limits listed above.

The project included construction of a 15 mgd wastewater reclamation plant, 122,000 ft of gravity sewers, 31,000 ft of force mains, and 6 pump

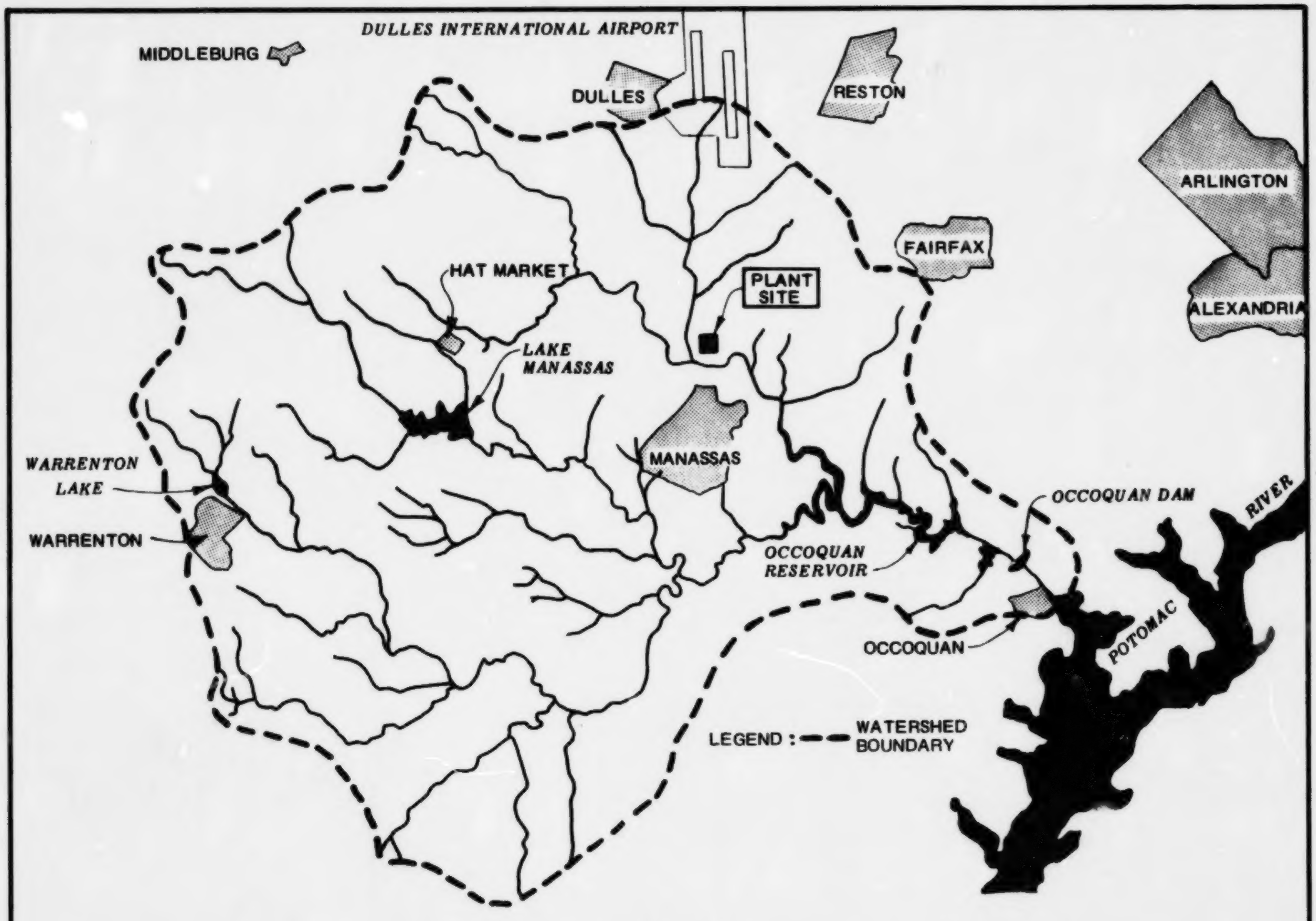
DULLES INTERNATIONAL AIRPORT
MIDDLEBURG
DULLES
RESTON
ARLINGTON
FAIRFAX
ALEXANDRIA
HAT MARKET
PLANT SITE
LAKE MANASSAS
MANASSAS
WARRENTON LAKE
WARRENTON
OCCOQUAN DAM
RIVER
OCCOQUAN RESERVOIR
POTOMAC
OCCOQUAN
LEGEND : WATERSHED BOUNDARY

Figure A-5. General location of Occoquan watershed and UOSA project.

stations. In addition, the system has extensive back-up units and emergency retention facilities to ensure reliability. The regional facilities became operational in June, 1978. The total cost of the project was $82 million, which was funded by a combination of authority revenue bonds and state and federal grants.

Basis of GAC System Design

The purpose of the activated carbon adsorption process is to remove the soluble organic compounds that are not readily removed by the upstream biological, chemical clarification, or filtration processes. Concentrations of the soluble organic compounds are expressed as mg/L of BOD, COD, and/or MBAS. Activated carbon adsorption is the most practical method for reducing the concentrations of these constituents in the wastewater to meet the treatment requirments.

Activated Carbon Adsorption

Number of carbon columns	Sixteen
Type	Upflow, countercurrent
Size of columns	12-ft dia x 24-ft SWD
Effective carbon depth	24 ft 8 in.
Carbon size	8 x 30 mesh

Normal Carbon Column Operation

Columns - in service	Eleven
Columns - spare	Five
Flow per column	1.0 mgd (694 gpm)
Surface loading rate	6.15 gpm/ft^2
Contact time	30 min

Maximum Loading Rate

Columns - in service	Eight
Columns - spare	Eight
Flow per column	1.37 mgd (951 gpm)
Surface loading rate	8.40 gpm/ft^2
Contact time	22 min

Estimated Carbon Dosage

Average	250 lb/mil gal
Maximum	450 lb/mil gal

Reactivation (based on carbon dosage 450 lb/mil gal)

Percent of carbon volume removed per reactivation cycle	10%
Frequency of reactivation with 30 min contact time	18.7 days

Frequency of reactivation with 20 min contact time	12.4 days
Weight of carbon regenerated per cycle per column	8,400 lb
Estimated makeup carbon	10%
Weight of makeup carbon per cycle per column	840 lb

Backwash

Supply	Filter effluent
Headloss to backwash	15 ft
Duration of backwash	15 min
Backwash rate	13.3 gpm/ft^2
Backwash rate per column	1,500 gpm

Operation

The 16 carbon columns are operated in parallel as upflow, countercurrent beds. They are arranged in four beds to provide maximum flexibility should one of the influent or effluent lines fail. At the present flow rate of 10.9 mgd, 11 columns are on line and 5 serve as standby units. This high level of redundancy was required since the plant effluent is discharged to a public water supply.

The optimum flow range is 694 to 951 gpm; lower flows pose the threat of anaerobic conditions developing in the columns, whereas higher flows cause escaping carbon fines to plug the outlet screens. Manual controls on the columns ensure the uninterrupted operation of the columns.

When the average effluent COD from the carbon bed reaches 10 mg/L, about 10 percent of the carbon is removed from the bottom of the bed; an equal amount of regenerated carbon is replaced in the top of the column. The frequency of withdrawal ranges between 12 and 34 days depending on the carbon dosage and contact time.

Periodic backwashing of the columns is necessary to reduce headlosses through them. This procedure is done when the headloss reaches 8 ft above the normal clean-bed headloss or at least every 3 days.

Process Control

The carbon column operation is monitored by the plant computer system. Performance is evaluated using data collected on a preestablished schedule. COD is used as the basic parameter for determining bed efficiency; declining efficiency is an indication that regeneration is necessary. Carbon loading is another operational control. A decrease in loading (normal range is 0.18 to 0.33 lb COD/lb carbon) is an indication that the regeneration process is not effective.

Basis of Reactivation Design

Annual operation (days)	
@ 250 lb/mil gal	83
@ 450 lb/mil gal	149
Daily spent carbon production (lb)	
@ 250 lb/mil gal	2,725
@ 450 lb/mil gal	4,905
Dewatering bins	
Number	Two
Volume - each ft^3	416
Feed conveyors (screw)	
Number	Two
Capacity - each lb/hr	500 dry reactivated carbon
- each lb/hr	1,500 spent wet carbon
Reactivation furnace	
Units in service	Two
Diameter	10-ft 9-in. OD
Number of hearths	Seven
Hearth loading	45 lb/ft^2/day
Capacity	12,000 lb/day
Fuel requirements	
LP gas	2,750 lb/day
Steam requirements	12,000 lb/day
Makeup carbon requirements @ 10%	
Regeneration loss	
@ 250 lb/mil gal	99,600 lb/yr
@ 450 lb/mil gal	178,800 lb/yr
Storage tanks	
Units - in service - spent or regenerated or virgin	One
Volume - ft^3	6,540 ft^3
Storage @ 250 lb/mgd	72 days/tank
Storage @ 450 lb/mgd	40 days/tank
Wet scrubber	
Type	Venturi
Stack gas	
Particulate emissions (max)	0.05 grains/SCF
Gas outlet temperature	120°F
Quench tank	
Units in service	One

Quenched carbon transfer pumps	
Units in service	One
Units spare	One
Type	Diaphragm
Capacity	500 lb/hr
De-fining, receiving, and transfer tanks	
Units in service	Two
Dry carbon volume	280 ft^3 each
Transfer capacity	8,400 lb/cycle each

SYSTEM PERFORMANCE

Reactivation Process

The plant includes a complete carbon reactivation system for: (1) receiving spent carbon from the carbon columns, (2) storing and dewatering the spent carbon, (3) feeding it at a controlled rate to the carbon regeneration furnace, (4) thermally reactivating the carbon, (5) quenching the carbon, (6) pumping the reactivated carbon to the transfer and de-fining tanks, (7) storing the reactivated and makeup carbon, (8) adding new makeup carbon, 9) conveying the reactivated carbon to the carbon columns, and (10) disposing of the furnace exhaust gases to the atmosphere (through a quencher and scrubber) without nuisance from dust, smoke, or odor.

Carbon withdrawn from the carbon columns for reactivation is discharged into two dewatering bins. Each dewatering bin holds about 416 ft^3 of carbon (12,368 lb dry weight), or a total of 832 ft^3 in the two tanks (24,736 lb dry weight). Typically however, only about 280 ft^3 (8,400 lb) is transferred at once, equivalent to 10 percent of the volume of one carbon column.

At least 10 minutes is allowed between filling a dewatering bin and withdrawal to the furnace to allow free water to drain from the carbon, leaving about 40 percent moisture on the carbon. Withdrawal of carbon from a dewatering bin is stopped before the screw conveyor is entirely empty to provide an air seal for the furnace. For continuous reactivation, the second dewatering bin is filled before the bin in use is empty.

The dewatered carbon is fed to the carbon regeneration furnace by one of two furnace dewatering feed conveyors. Each feed conveyor is driven by a 2-hp motor with a mechanical adjustable speed drive.

The multiple hearth furnace has a capacity of 12,000 lb carbon/day. The carbon is moved across each hearth by rotating stainless steel rabble arms equipped with vertically-oriented stainless steel rabble teeth. A modulating burner control system is provided for each hearth so that the desired temperature on it can be closely and independently maintained. In the furnace, the carbon is thermally reactivated in the presence of steam. Cooling air is provided to the central shaft by a shaft cooling air blower (M-1013) driven by a 15-hp motor. Combustion air is provided to six hearths in the furnace by the use of a combustion air blower. An afterburner blower provides air to the top hearth of the furnace.

The furnace exhaust gases are discharged through a quencher to precool them before scrubbing, and through a scrubber to capture particulate matter and to reduce the exit gas temperature to 120°F. An induced draft fan discharges the furnace gas to either the CO_2 compressor or to the atmosphere.

Furnace operation is monitored routinely by tests for the apparent density of the carbon, supplemented at times by tests for Iodine Number, ash content, adsorption isotherms, or other laboratory analyses to check the activity of the regenerated carbon.

Under normal operation (plant flow at 10.9 mgd and carbon dosage 250 lb/mil gal), the regeneration furnace is in use about 23 percent of the time.

The carbon is discharged from the furnace by gravity into a quench tank where the carbon is cooled and put into water slurry. The carbon slurry is then pumped by either of two diaphragm slurry pumps that take suction from the quench tank and discharge into the two transfer and de-fining tanks. The pumps are operated by compressed air, and each delivers 13 to 20 gpm of slurry.

Each of the two transfer and de-fining tanks will hold about 280 ft^3 (8,400 lb dry weight) of carbon, or a total of 560 ft^3 (16,800 lb) in the two tanks. A flow of water directed upward through the tank flushes the fines to the first-stage recarbonation basin with the wash water; the de-fined carbon remains in the tank. Carbon is transferred from the de-fining tanks to the top of the carbon columns by pressurizing the de-fining tanks with water through a pressure water connection in the top of the tanks. Water flow is established through the drainline first before carbon is released from the bottom of the tank. The water flow is continued until the tank and pipeline have been flushed free of carbon.

A temporary storage tank is provided for spent carbon in case the reactivation furnace is out of operation. When the furnace is in operation, the carbon is transferred through the de-fining tank, to the dewatering tanks, and processed through the reactivaton furnace as per normal operations. Virgin carbon can also be stored in this tank if necessary. Sufficient virgin carbon is stored to operate the carbon adsorption process for 1 month without the benefit of the reactivation system.

Carbon losses due to attrition and excess burn-off range from 5 to 10 percent of the carbon regenerated.

Bags of virgin (makeup) carbon are added to the de-fining tanks by a virgin carbon conveyor. The conveyor can discharge 40 lb/min of granulated carbon. It works in conjunction with a vibrating virgin-carbon shaker that feeds carbon granules onto the conveyor. An exhaust fan directs the dust from the hopper to the scrubber.

A portable eductor can also be used to convey virgin carbon (bulk in trucks) to the de-fining tanks. This unit is capable of supplying 36 gpm and 100 psi of water. The eductor pump capacity is 100 gpm.

A carbon dioxide compressor is provided to compress the stack gas for use in recarbonation.

Instrumentation and Controls

A central control panel is provided to monitor the carbon regeneration system operation and to permit the system to be manually started and stopped and automatically controlled. The most important operating variables are indicated and/or recorded on the panel as summarized below:

Alarms

High and low dewatering tank level (2)
Combustion low air pressure
Furnace high temperature
Flue exhaust - high temperature
I.D. fan - high inlet temperature
Draft loss
Cooling air stack - high temperature
Quench tank high level - water
Quench tank low level - water
Scrubber temperature - high
Transfer and de-fining tank - high level
Induced draft fan - vibration
Separator - high

All alarm functions are annunciated.

Indicators

Dewatering bin bottom valve (2)
Feed conveyor speed (2)
Hearth temperature (6)
Furnace draft and pressure
I.D. fan outlet temperature
Main exhaust stack temperature

Controllers and Switches

Furnace feed conveyors (2)
Dewatering bin bottom valves (2)
Purge
Burner controls
Afterburner turboblower
Combustion blower
Eductor water pump
I.D. fan

Center shaft drive
Cooling air fan
Center shaft speed
CO_2 compressor

A temperature recorder records the temperature of each of the seven furnace hearths, the scrubber inlet and outlet gas, the furnace gas outlet, and center shaft outlet.

A multipoint draft gauge indicates the draft at critical points in the combustion air and gas system.

The furnace is equipped with an automatic draft control to maintain preset draft on the furnace. An automatic afterburner air injection system is also included.

CAPITAL AND OPERATION AND MAINTENANCE

Capital Cost

The capital cost of the carbon system has not been precisely defined. The carbon adsorption columns and the carbon regeneration furnace were portions of 3 lump sum contracts. The capital costs were approximated by using the contractors' break out for payment purposes and apportioning the miscellaneous costs.

Carbon adsorption columns	$2,250,000
Carbon regeneration system	1,630,000
Total carbon system	3,880,000

Operation and Maintenance Cost

The O&M costs for each million gallon for 1979 are estimated at:

Personnel	$13.46
Carbon	8.28
Fuel	7.00
Electricity	4.00
Replacements, repairs, and miscellaneous	17.26
Total O&M cost	$50.00/mil/gal

These estimates are based on very limited data. Carbon has been regenerated only twice, and the furnace has not yet been accepted from the supplier.

CASE HISTORY NO. 4
AMERICAN CYANAMID CO.
ORGANIC CHEMICALS DIVISION
BOUND BROOK, NEW JERSEY
INDUSTRIAL WASTEWATER TREATMENT

HISTORY AND INTRODUCTION

The Bound Brook, New Jersey, plant of American Cyanamid Company employs 2,200 persons and produces over 1,000 different products including dyes, chemical intermediates, organic pigments, plastic additives, pharmaceuticals, fine-chemicals, agricultural chemicals, elastomers, and rubber chemicals. The multiple waste discharges from the production operations are combined with cooling water, sanitary sewage, and stormwater runoff from the plant area to form a single effluent stream that is processed in an AWT facility. Typical ranges of BOD, COD, Color, and TOC in the raw waste stream are shown in Table A-10.

TABLE A-10. INFLUENT WASTEWATER CHARACTERISTICS

Parameter	Concentration range
BOD	270 - 400 mg/L
COD	1,000 - 1,400 mg/L
TOC	260 - 350 mg/L
Color	400 - 600 CDAPHA units

Wastewater treatment has been a major part of the Bound Brook operation for over 30 years. As wastewater technology has progressed with time, the Bound Brook plant has made significant improvements to its wastewater treatment facilities. In the late 1930's, a primary treatment plant was installed at a cost of $500,000. This plant included a 19 mil gal equalization basin, a lime neutralization facility to neutralize 30 tons of sulfuric acid a day, and a 60 mil gal primary settling lagoon.

Beginning in 1949, extensive laboratory and pilot plant studies were initiated to procure design data for the construction of an activated sludge treatment plant. This facility was built in 1957 at a cost of $4,500,000 and placed into operation in 1958. The secondary waste treatment facilities consist of six aeration basins, each having a capacity of 3.3 mil gal, six secondary clarifiers, and a chlorine contact chamber. Figure A-6 illustrates the secondary treatment facilities.

The secondary waste treatment facilities provided more than a 90 percent reduction in BOD and approximately a 65 percent reduction in TOC and COD.

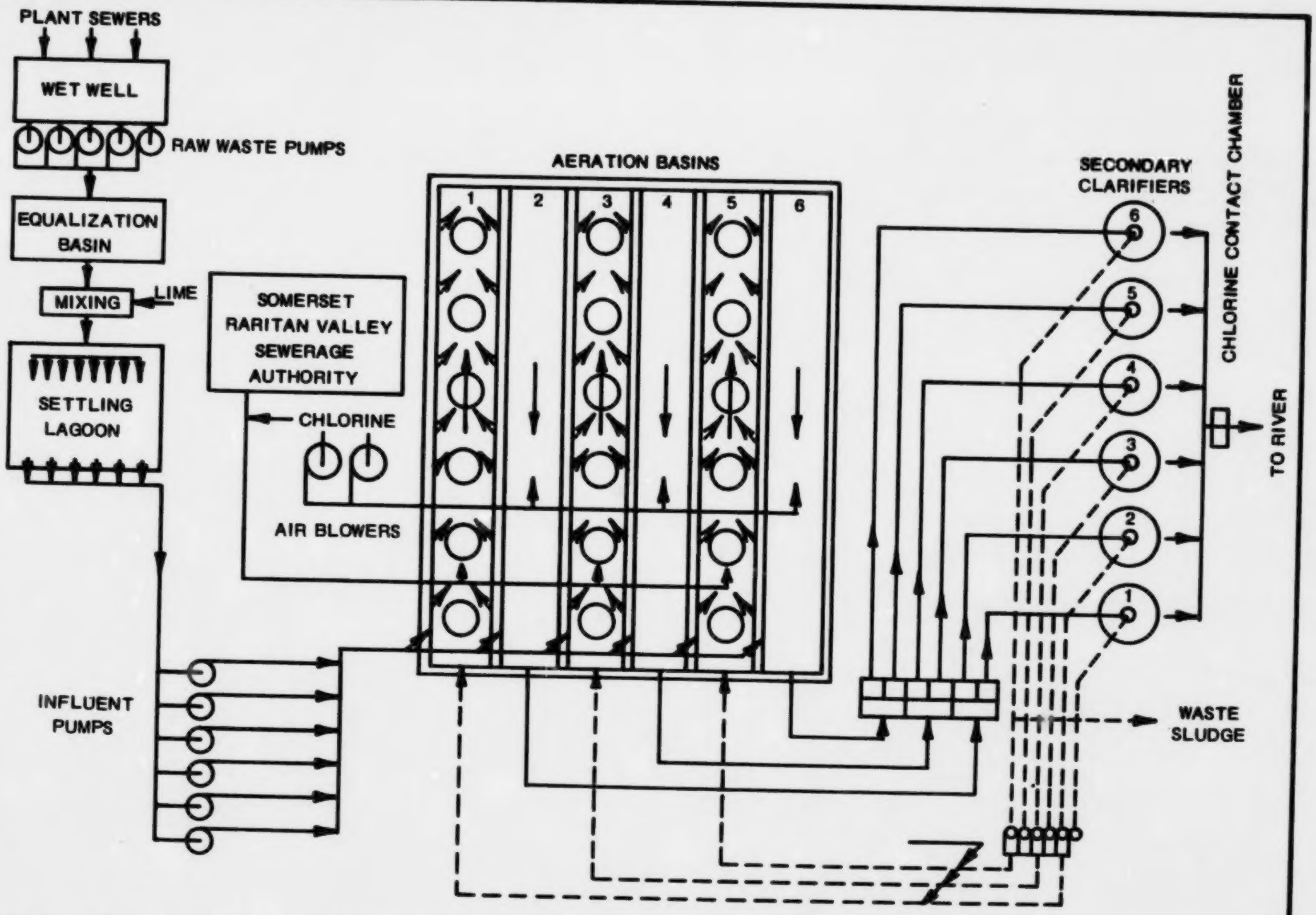
PLANT SEWERS
WET WELL
RAW WASTE PUMPS
EQUALIZATION BASIN
MIXING
LIME
SETTLING LAGOON
SOMERSET RARITAN VALLEY SEWERAGE AUTHORITY
CHLORINE
AIR BLOWERS
INFLUENT PUMPS
AERATION BASINS
1
2
3
4
5
6
SECONDARY CLARIFIERS
6
5
4
3
2
1
CHLORINE CONTACT CHAMBER
TO RIVER
WASTE SLUDGE

Figure A-6. Waste treatment plant flow diagram before construction of AWT plant; American Cyanamid Company, Bound Brook, NJ.

Unfortunately, many of the organic compounds present in the raw wastewater are resistant to biodegradation, and significant quantities of nonbiodegradable organics are present in the secondary effluent. In 1971, it became evident that additional treatment was needed, particularly for removal of color, odor, toxicity, and suspended solids. At times during the year, because the Bound Brook plant effluent constitutes up to 25 percent of the nearby Raritan River, it must remain high in quality.

Two alternatives were considered for upgrading the Bound Brook plant effluent. They were: (1) heavier emphasis on at-source treatment or control in the manufacturing areas and, (2) additional end-of-pipe treatment (AWT) to supplement biological treatment. Source control or treatment was not considered feasible; therefore, AWT processes were studied.

- Bench Scale Studies were conducted to evaluate activated carbon adsorption, high lime treatment, and ozonation. Of the three processes, carbon adsorption was the most favorable for reducing color, foam, and refractory organics.
- Pilot Plant Studies of granular and powdered activated carbon were used to determine which was more effective and least costly. From these, the design criteria for a full-scale GAC plant were determined.

The advanced treatment plant that was put into service in 1977 consists of multimedia filtration, carbon adsorption, transport facilities, and carbon reactivation (Figure A-7).

DESIGN DATA

The design data for the carbon adsorption system for Bound Brook as determined from the extensive studies conducted is as follows:

Carbon contactors:	
Type	Upflow, expanded bed
Number	10 units piped in parallel
Size	16-ft diameter, 40-ft straight sidewall; 45° cone-shaped columns
Flow	8 gpm/ft^2
Detention time	30 min
Carbon	8 x 30 mesh GAC 30-ft depth in each column
Reactivation procedure	5 percent pulse of exhausted carbon removed from bottom of each column daily; equivalent amount of fresh carbon replaced in top of column; Carbon slurry transferred to equalization vessel;

	Slurry dewatered by screw conveyors leading to furnace; Reactivated carbon quenched to ambient temperature and transferred to storage tank.
Reactivation furnace	
Type	8-hearth furnace with afterburner
Size	25-ft, 9-in. diameter
Temperature	1750°F
Capacity	122,000 lb/day average; 152,000 lb/day maximum
Carbon loss	9%

SYSTEM STARTUP AND OPERATION

Carbon Adsorption

Although the carbon adsorption towers were started up with a minimum of problems, several problems are worthy of note.

As the start-up and operation of the facility progressed into the winter months, the areas of the plant that had not been adequately heat traced and insulated for cold weather operation became immediately apparent. Approximately 4 miles of electrical tracing were needed to adequately heat those areas.

During the start-up, it was found that each tower has to be pulsed every 30 to 36 hours. Longer frequencies result in a buildup of suspended solids on the carbon in the lower sections of the towers; the buildup causes the carbon to bridge across the cone bottom when an attempt is made to pulse the tower. The bridging can be broken by reversing the pulse flow direction, but this procedure creates excessive fines in the tower effluent. The upset can be accommodated only by holding the tower on recycle for an extended time.

Another unexpected problem was the result of the free fall of water from the adsorbers effluent launders into the main 36-in. final effluent line. Air was entrained by the free fall (approximately 10 ft in the 36-in. line) and caused a severe vibration problem. The 36-in. line had been trapped to provide a sidestream supply to booster pumps feeding the regeneration furnace scrubbers. Removing the trap to provide venting solved the vibration problem but, in turn, necessitated installing an air disengagement tank for the scrubber pump water supply.

In the upflow design, carbon fines are purged from a tower during pulsing. During this operation, the tower is placed on recycle to prevent any carbon fines and other suspended solids generated by the upset of the carbon bed from leaving with the final effluent. The initial design returned the adsorber recycle stream containing fines to the multimedia filter influent. The carbon fines, which range in size from 10 to 100 microns, caused extremely rapid surface blinding of the filter media. As a result, it was necessary to redirect the fine-bearing recycle streams to the head of the secondary treatment plant. The carbon fines are now purged from the secondary plant with the waste sludge.

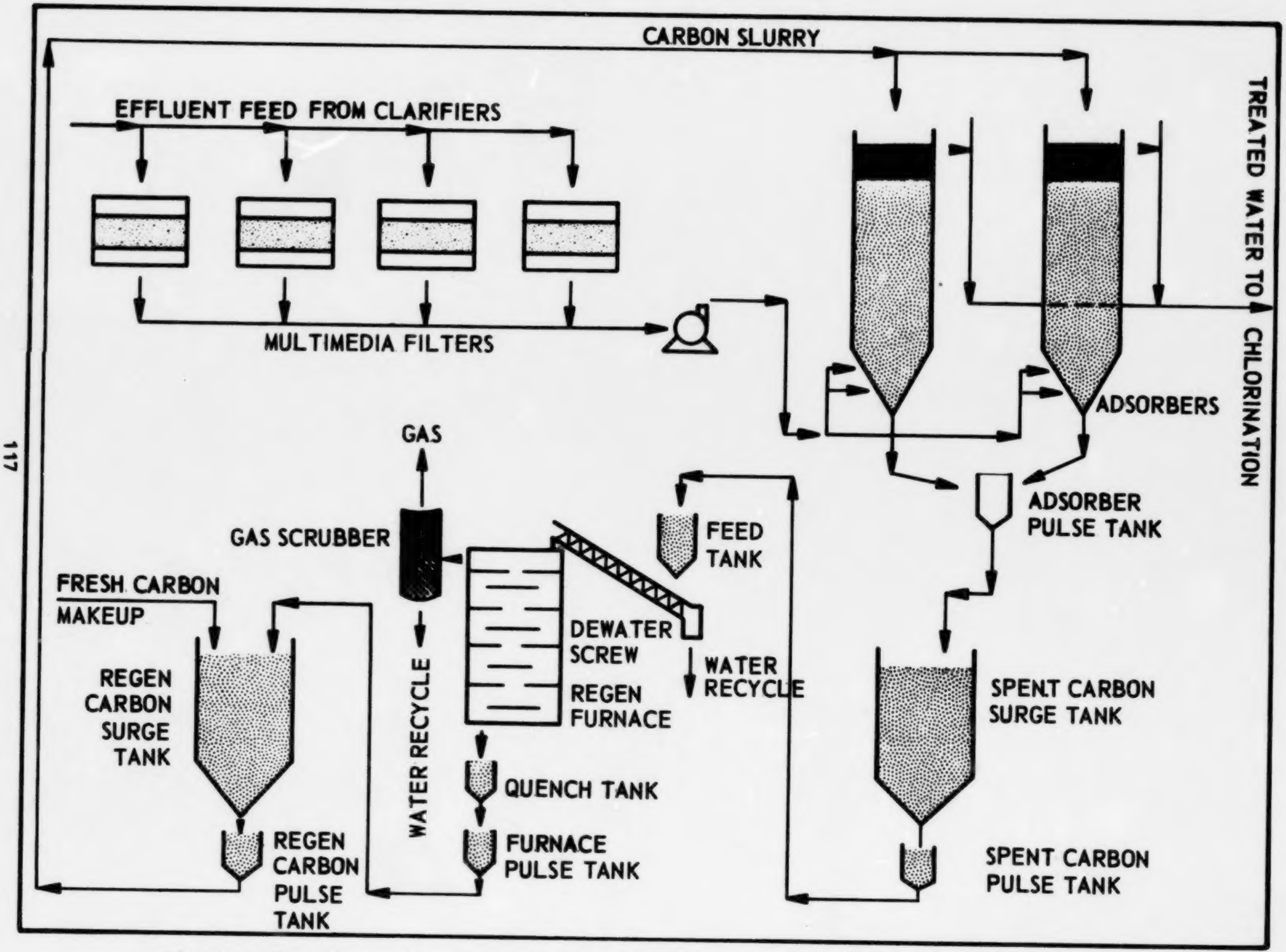
CARBON SLURRY
EFFLUENT FEED FROM CLARIFIERS
MULTIMEDIA FILTERS
TREATED WATER TO CHLORINATION
ADSORBERS
ADSORBER PULSE TANK
SPENT CARBON SURGE TANK
SPENT CARBON PULSE TANK
FEED TANK
WATER RECYCLE
DEWATER SCREW
REGEN FURNACE
GAS
GAS SCRUBBER
WATER RECYCLE
QUENCH TANK
FURNACE PULSE TANK
FRESH CARBON MAKEUP
REGEN CARBON SURGE TANK
REGEN CARBON PULSE TANK

Figure A-7. Advanced waste treatment flow diagram, American Cyanamid Company, NJ.

Carbon Handling

All carbon in the AWT plant is conveyed hydraulically. All of the carbon movement into and out of the adsorbers storage tanks and reactivation furnace is controlled automatically by a programmable controller utilizing 8K of memory. No major problems were encountered with the start-up of the programmer itself; however, some hardware problems are worthy of discussion.

Standard pivot arm microswitches are used throughout the carbon handling system to detect and verify valve positions. This type of switch proved very troublesome in an outdoor installation, especially in freezing weather. Carbon level sensing also proved to be a difficult proposition. Nuclear carbon level and carbon-water density instruments were initially installed to detect high carbon levels and empty pipeline points for the automatic carbon pulsing programs. Carbon levels proved difficult to detect by this system. After a period of trial and error, it was found that ultrasonic probes would detect carbon levels accurately and reliably.

The carbon handling systems utilize piping of 4 in. and 6 in. Pipeline velocities are controlled at approximately 3.5 ft/sec. Slurry density during the pulse period averages 0.35 lb carbon/lb water. At these conditions, very few line blockages occur and attrition losses are minimized. Some difficulties were initially encountered when the carbon was moved through lengths of pipe exceeding 200 equivalent ft and to elevations exceeding 80 ft. Modifications had to be made to these flow conditions to transport the carbon reliably over the longer runs to the higher elevations in the plant. The basic carbon transport loops utilizing the water pulsing method are designed to permit reversal of flow through most of the system. This allows clearing of carbon line blockages with relative ease.

Carbon Reactivation

The spent carbon is reactivated in a 25-ft 9-in. diameter multiple hearth furnace. A number of start-up problems were encountered with this unit. One of the first problems centered around the spent carbon feed system, which consists of a holding tank, an automatic discharge valve, and a dewatering screw. The mechanical problems were readily solved, but the balancing of the carbon flow into and out of the dewatering screw and into the furnace was more difficult. A very precise balancing was required to ensure a constant feed rate into the furnace. Variations in the feed rate cause temperature fluctuations that are reflected through the upper hearths. To control the furnace operation, a steady temperature profile must be set and maintained. Good control is needed over the carbon discharge flow rate. The carbon tends to discharge from the furnace in slugs as the rabble teeth move the carbon to the discharge point. As the carbon is quenched, steam is generated, and as the steam rises through the furnace, an uncontrollable draft fluctuation occurs. It was necessary to throttle and balance the carbon discharge flow to maintain a controllable furnace internal pressure. Separation of the two steps of carbon dewatering and conveying by installation of dewatering tanks ahead of the screw conveyors might have avoided these problems.

The last problem with the reactivation furnace concerned the very rapid and unexpected failure of two hearths after approximately 3 months of operation. Hearth No. 7 failed somewhat dramatically while the furnace was operating at design temperature. Approximately 75 percent of the hearth inverted and then collapsed when the furnace cooled down. During the cool-down, Hearth No. 5 flattened to the point that it had to be removed also. Dependence on a single reactivation unit necessitated resumption of operation with two hearths removed. Carbon reactivated under these conditions was acceptable, with apparent bulk densities in the 0.49 to 0.51 gm/cc range at feed rates of 90,000 lb/day.

Reactivation performance has been difficult to control and optimize because of the size of the furnace. It can take several days of operation to reach a desired operating point. When an operating variable is altered, several hours are required for the furnace to reach equilibrium and reflect the change. The constantly changing nature of the primary effluent discharge from the Bound Brook plant produces a varying adsorbate loading on the carbon that further complicates determining the optimum furnace conditions. These problems have also made it difficult to determine accurately the turndown capabilities of the reactivation funace. Acceptable bulk densities can be obtained by relying on operating experience to set reactivation conditions, but optimization of these conditions has not yet been achieved.

Most of the described start-up experiences and problems probably are typical for a 20 AWT facility. The problems, although somewhat peculiar to a chemicals manufacturing plant, have been resolved. The overall plant has been in continuous operation since December 1977, and treatment performance has been basically as predicted by the 40 gpm pilot plant.

SYSTEM PERFORMANCE

The most meaningful performance data for the Bound Brook facility were collected during the pilot plant studies. Figure A-8 shows the TOC breakthrough curves developed from one run of the 5-in. diameter carbon columns. The four columns were operated as downflow packed bed units piped in series.

Refinement of the pilot studies led to the operation of a 30-in. diameter pilot plant testing program. Figure A-9 shows the performance of this system relative to the removal of TOC. In this study, a single column was operated as an upflow expanded bed unit. A pulse of exhausted carbon was removed from the bottom of the column each day and an equivalent amount of fresh carbon (either virgin or regenerated) was added to the top of the unit. This unit was the prototype (in terms of operation) for the full scale plant.

Laboratory analyses of dissolved solids and nitrogen were run on the influent and effluent of the initial 5-in. pilot system. Average dissolved solids and ammonia nitrogen removals were minimal--3 and 2 percent, respectively. On the other hand, the average organic nitrogen removal was 85 percent.

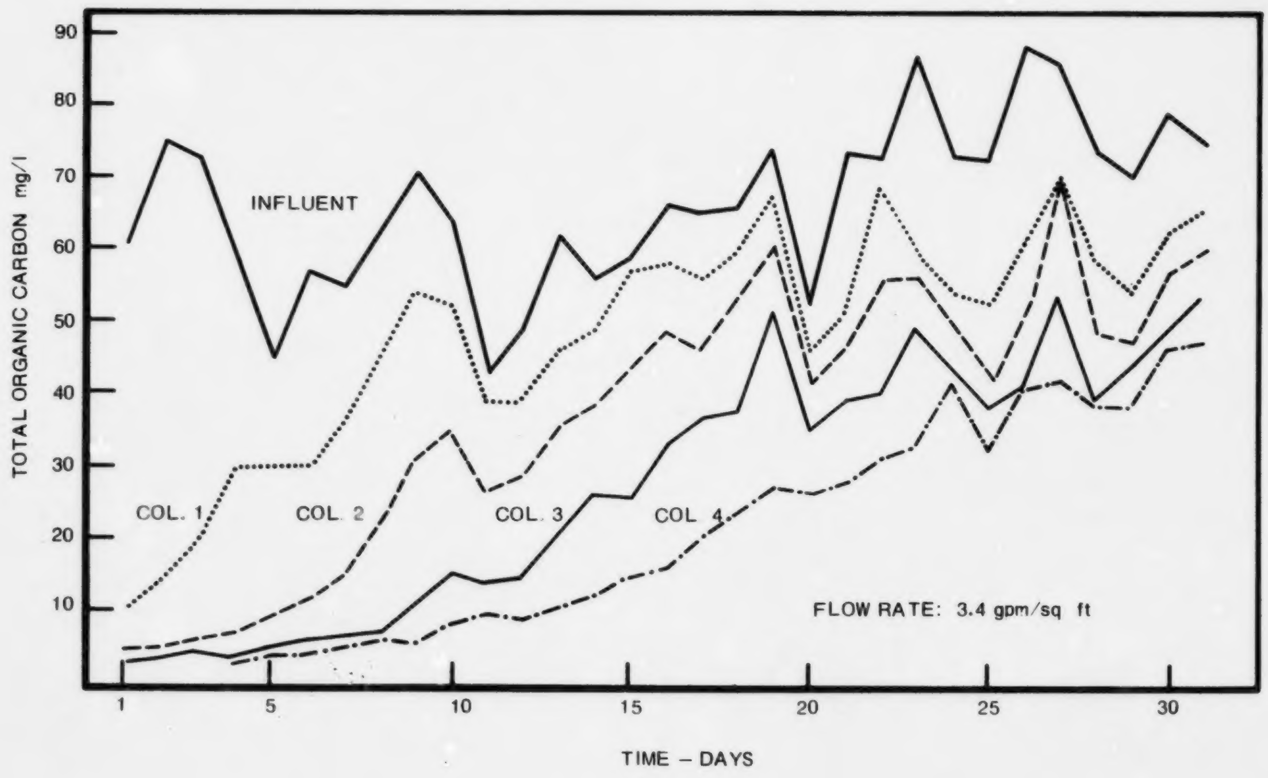

Figure A-8. Breakthrough curve for total organic carbon; run 2, 5 in. diameter columns.

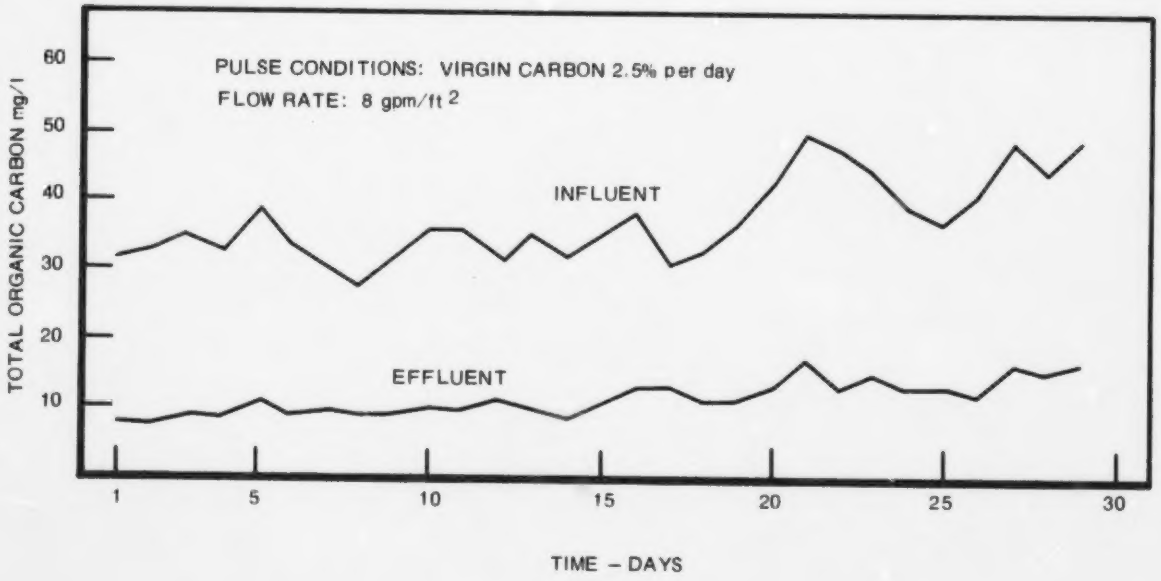

Figure A-9. Total organic carbon removal; 30-in. diameter pilot carbon column.

CAPITAL AND OPERATION AND MAINTENANCE COSTS

Detailed cost estimates for this facility are not available; however, the entire Bound Brook AWT plant cost $23 million. The annual operating costs for these facilities currently exceed $9 million.

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CASE HISTORY NO. 5
VALLEJO SANITATION AND FLOOD CONTROL DISTRICT
VALLEJO, CALIFORNIA
PHYSICAL-CHEMICAL WASTEWATER TREATMENT

HISTORY AND INTRODUCTION

In 1972, work was started to convert Vallejo's existing conventional 7 mgd primary wastewater treatment plant to a 13 mgd physical-chemical plant utilizing GAC. The plant was to produce an effluent with an average BOD of 30 mg/L and an average suspended solids of 30 mg/L. The decision to use physicalchemical treatment rather than biological secondary treatment was reached after engineering studies of the existing treatment facilities and after pilot plant tests were completed. Plant design and construction were completed in 1978. The revised and enlarged plant has been in start-up and operation since that time. Some mechanical problems have been experienced, but the physical-chemical treatment plant appears to be capable of meeting the discharge standards for Carquinez Strait. This is based on rather limited operating experience.

DESIGN DATA

The plant is designed for an average dry weather flow of 13 mgd and a maximum daily flow of 27.7 mgd (Figure A-10). The plant processes include:

1. Prechlorination
2. Screening
3. Grit removal
4. Lime addition to pH = 10.2
5. Polymer addition
6. Rapid mixing
7. Flocculation
8. Sedimentation
9. Single stage recarbonation with standby hydrochloric acid feed to pH = 8.0
10. Granular activated carbon adsorption
11. Chlorination
12. Polymer addition
13. Dual media filtration
14. Sludge storage
15. Vacuum filtration of sludge
16. GAC reactivation in a multiple hearth furnace

The removal factors of the plant unit processes at mean daily flow are given in Table A-11.

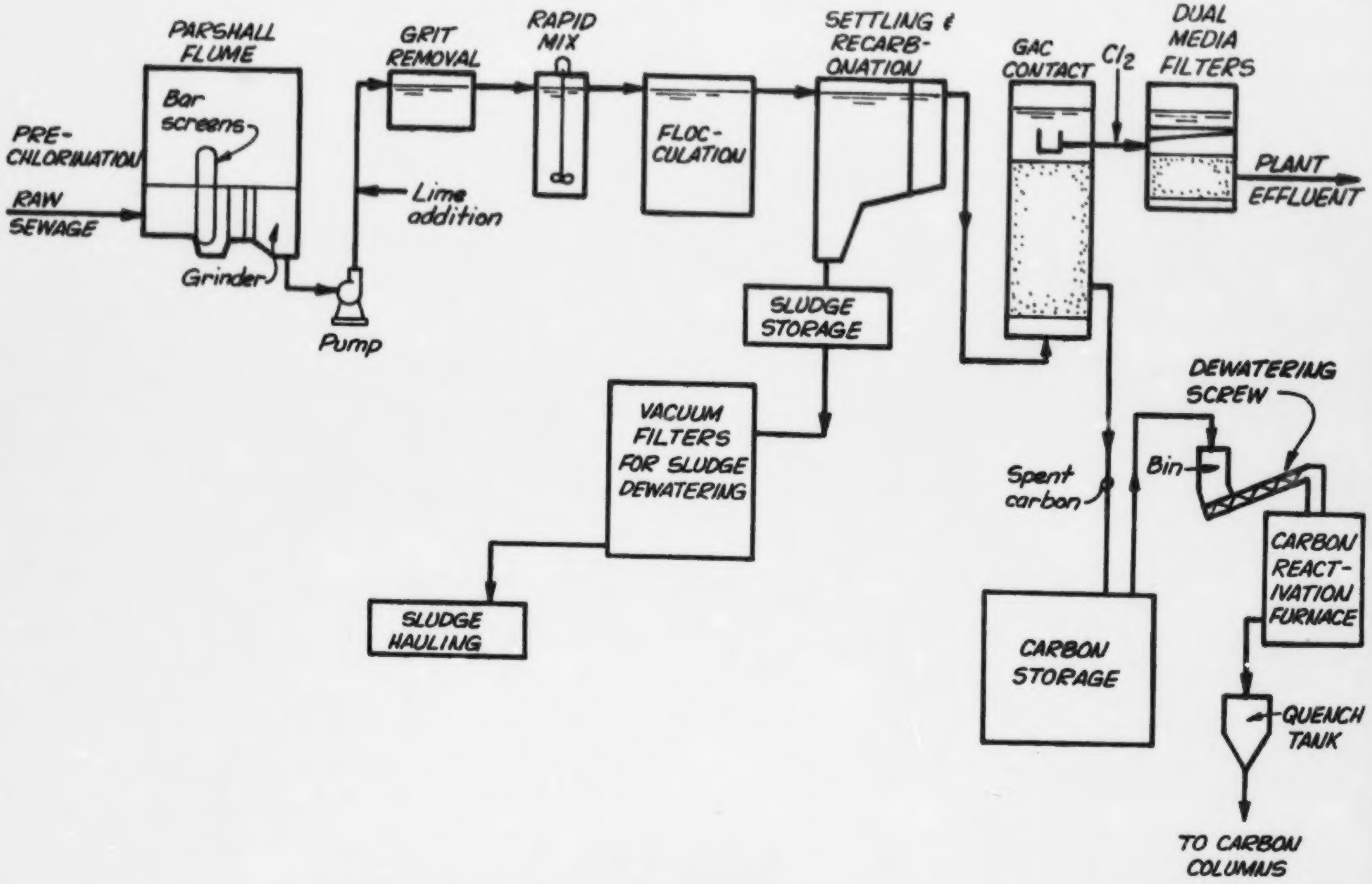
PARSHALL FLUME
Bar screens
PRE-CHLORINATION
RAW SEWAGE
Grinder
Pump
GRIT REMOVAL
Lime addition
RAPID MIX
FLOC-CULATION
SETTLING & RECARB-ONATION
SLUDGE STORAGE
VACUUM FILTERS FOR SLUDGE DEWATERING
SLUDGE HAULING
GAC CONTACT
Cl_2
DUAL MEDIA FILTERS
PLANT EFFLUENT
Spent carbon
CARBON STORAGE
DEWATERING SCREW
Bin
CARBON REACT-IVATION FURNACE
QUENCH TANK
TO CARBON COLUMNS

Figure A-10. Flow diagram of Vallejo wastewater physical-chemical treatment plant, Vallejo, CA.

TABLE A-11. REMOVAL FACTORS OF UNIT PROCESSES AT MEAN DAILY FLOW

	Data for 6 months ending 8-31-79			Design estimates based on pilot plant tests		
Element	Raw sewage	Floc. & sed.	GAC adsorption	Filtration	Effluent	Unit
COD	424	424 to 140	175 to 90	90 to 45	45	mg/L
		= 284	= 85	= 45		mg/L
		67%	49%	50%	89%*	percent
BOD	223	228 to 80	104 to 45	45 to 25	25	mg/L
		= 143	= 59	= 20		mg/L
		64%	57%	45%	89.5%	percent
SS	368	368 to 70	66 to 22	22 to 7	7	mg/L
		= 298	= 44	= 15		mg/L
		81%	67%	46%	97%*	percent

*Overall removal.

Basis of GAC System Design

At low flows, carbon columns are taken off the line as necessary, to limit carbon contact time to not more than 30 minutes, limiting the time avoids hydrogen sulfide production that might occur under longer detention times. The content of carbon column influent is about 5 mg/L. Figure A-11 is a crosssection through a carbon bed.

Carbon adsorption:	Min.	Avg. or Fixed	Max
Number units (contactors		Six	
Size-length, width, depth		18 ft x 30 ft	
Area per unit		324 ft^2	
Flow rate (upflow mode)		6 gpm/ft^2 @13 mgd	10 gpm/ft^2 @28 mgd
Flow per unit		1,540 gpm	3,300 gpm
Carbon size		12 x 40 mesh	
Carbon bed expansion		10%	40%
Carbon head loss		4 ft	5 ft
Air scrubbing		5 $scfm/ft^2$	
Flushing rate		15 gpm/ft^2	
Carbon bed expansion when flushing		50%	
Carbon head loss when flushing		5.92 ft	
Carbon depth		16 ft	
Carbon volume per unit		5,190 ft^3	
Carbon active capacity in 6 beds		31,000 ft^3	

Carbon adsorption:	Min.	Avg. or Fixed	Max
Carbon bulk density, drained	24 lb/ft^3	27 lb/ft^3	30 lb/ft^3
Carbon contact time		25.2 min.	11.7 min
Carbon active capacity in 6 beds		840,000 lb	
Carbon inactive storage in 2 beds		280,000 (storage)lb	
Carbon inventory		1,120,000 lb	
Carbon adsorption		0.5 lb COD/lb carbon	
Carbon dose		1,410 lb/mil gal	
Carbon exhaust rate		18,400 lb/day	
Exhaustion of active carbon		46 days	
Carbon loss per regeneration		7.5%	
Carbon refill rate		505,000 lb/yr	

Carbon reactivation:	
Number units	One
Total hearth area	402 ft^2
Number hearths	Six; BSP furnace
Diameter hearths (I.D.)	12 ft I.D.
Furnace loading	3 lb carbon/ft^2/hr
Furnace loading	1,206 lb carbon/hr
Furnace operation time	64%
Operation	19 24-hr days/mo
Residence time	1 hr
Steam required	1 lb steam/lb carbon
Afterburner	One
Scrubber	One
Carbon dewater unti	One
Carbon quenching unit	One
Carbon transport pumps	Two

Spent carbon is moved directly from the contactors to a small bin above the dewatering and conveying screw that feeds the reactivation furnace using eductors permanently mounted at four fixed locations in each contactor. Eductors also convey the reactivated carbon back to two extra contactors, which are used as storage for makeup and reactivated carbon.

The construction specifications for the project included a requirement for testing the performance of the carbon reactivation system. A copy of this report concludes this plant description.

CAPITAL OPERATION AND MAINTENANCE COSTS

The available construction cost data are limited to those given in Table A-12.

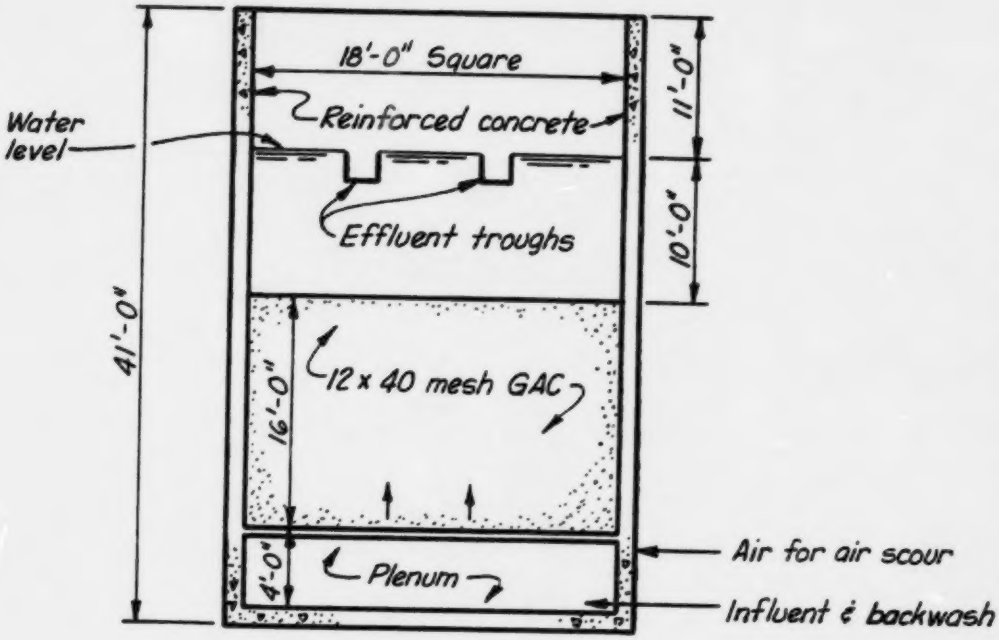
18'-0" Square
Water level
Reinforced concrete
11'-0"
10'-0"
Effluent troughs
41'-0"
16'-0"
12 x 40 mesh GAC
Air for air scour
4'-0"
Plenum
Influent & backwash

Figure A-11. Cross section through carbon column (expanded bed upflow), Vallejo Sanitation and Flood Control District, CA.

TABLE A-12. GAC SYSTEM CONSTRUCTION COST SUMMARY*

Item	Bid price†
GAC	$ 443,000
GAC contactors	2,486,000
Gac regeneration system	1,430,000

*GAC contactors bid price includes all intra-process piping and instrumentation and GAC storage beds. GAC regeneration system bid price includes a gas cooling, conveyance, and compressor system used in the recarbonation process. No bid price break out is available for this gas system.

†Bids were received in October 1974.

The cost data for O&M is also rather limited because of the short time the plant has been in full operation.

Plant operators estimate that they spend 3 hr/day/shift, or a total of 9 hr/day, in backwashing and air scouring the carbon adsorbers. At $11 per hour, this comes to a total of $99 per day for operation of the carbon adsorption system.

Cost data for GAC reactivation are not available at this time.

PERFORMANCE TEST REPORT*

CARBON REGENERATION FURNACE
VALLEJO, CALIFORNIA

JOB NUMBER 5014-21†

This performance test was successfully conducted on the 12'-9" O.D. x 7 Hearth Carbon Regeneration Furnace System to meet the objectives of specified carbon loss and stable furnace operation. The test was conducted starting at 10:35 AM, November 15, 1978 and ending at noon on November 17, 1978.

The activated carbon regenerated was ICI America granular carbon, 12 x 40 mesh, which had been used to adsorb organics from line treated and recarbonated sewage at the Vallejo Sewage Treatment Plant.

The individuals involved during the testing periods were:

BSP Envirotech

Gene Augustine
Tom Hynes
Jerry Isaak
Scott Hume
Ivan Joya

ICI America

Lou Billello
Ron Sheaffer

Kaiser Engineers

Robert C. Carr

C. Norman Peterson

Dave McKissic
Larry Thompson

SUMMARY AND CONCLUSIONS

The test was conducted in general accordance with the Performance Test Procedure of August 21, 1978 which also provided for a Pre-performance Test operating period.

The following objectives were accomplished during the Pre-performance Test period:

1. The method of measuring the carbon bed depth was established and agreed upon by Kaiser Engineers, ICI and BSP.
2. The rotary feed valve was calibrated to establish a curve of furnace feed rate vs. rotary valve set point.

---

*December 1, 1978. I. Joya, Senior Process Engineer
†BSP Division of Envirotech Corporation

3. The carbon regeneration system was operated for approximately five days during the week of November 6 and early in the week of November 13 to establish reliable operation prior to the Performance Test.

During the 48-hour Performance Test of November 15 - 17, 1978, the following objectives were accomplished:

1. The carbon furnace was continuously operated at a feed rate of approximately 1310 lb/hr which is in excess of the specified 1206 lb/hr.

2. The carbon loss from adsorber through regeneration and returned to adsorber was 3.5% which is well within the specified loss of 5.5% maximum.

3. Regeneration of the carbon was successful based on apparent density and iodine number analyses made on composite samples collected during the test. The average analytical results are summarized below and the complete report by the independent laboratory appears in Appendix III.

	Spent carbon	Regenerated carbon	Virgin carbon*
Apparent density, gm/cc	.441	.403	.4
Iodine number	.451	634	600 min.

*Specification values. Abrasion number, 25 max.

4. Sieve analysis of the collected samples indicated no significant change in particle size distribution. In all cases, the spent and regenerated samples exhibited the virgin carbon specification values of no more than 5% of the particles larger than 12 mesh and no more than 5% of the particles smaller than 40 mesh.

5. Successful regeneration was accomplished at temperatures in the neighborhood of 1500°F.

TEST PROCEDURES

Bed Height Measurement

Measurements were made to establish bed height in Test Adsorber No. 2 before and after the 48-hour regeneration. The method of measurement was first to establish a backwashed and settled bed with a surface as level as possible, this was done by:

a. air scouring for 5 minutes,
b. settling until most of the air was evolved,
c. backwashing at high flow rate for 10 minutes,
d. settling for 10 minutes.

Measurements were then taken at 17 points within the adsorber from a reference point at the top edge down to the top of the bed. Each measurement was made by suspending a weighted screen attached to a steel measuring tape. The bed measurements recorded appear in Appendix I.

This method of measurement was established as reliable by Kaiser and BSP during Pre-preformance Test trials of August 12 and 14, 1978.

Feed Rate Measurement

Furnace feed rate was established by calibrating the rotary feed valve which regulates the flow of carbon from the furnace feed tank to the dewatering screw. This calibration was made by routing the valve discharge into a 20 gallon drum; then for several valve set points, the time interval, revolutions and volume of carbon delivered were measured. Using these values along with a carbon density of 25 dry lb/cf, a graph of feed rate vs. valve set point was made. This graph appears in Appendix II. During the test, a valve set point of 1.8 was maintained.

Carbon Loss Determination

Prior to the test, the 5.5% specified carbon loss was equated to a loss of bed height of about 4 3/4 inches. This is indicated in a letter of September 1, 1978 from Kaiser Engineers which appears in Appendix I. The calculations to arrive at the value of 4 3/4 inches are as follows:

$$\text{Allowable Carbon Loss} = 1208\ \frac{\text{lb}}{\text{hr}} \times 48\ \text{hr} \times 0.055 = 3189\ \text{lb.}$$

$$\text{Carbon Bed Inventory} = \frac{18\ \text{ft.} \times 18\ \text{ft.} \times 25\ \text{lb/ft}^3}{12\ \text{in/ft.}} = 675\ \text{lb/in.}$$

$$\begin{array}{c}\text{Allowable Loss of Bed}\\ \text{Height}\end{array} = \frac{3189\ \text{lb}}{675\ \text{lb/in}} = 4.72\ \text{say}\ 4\ 3/4\ \text{in.}$$

The actual loss of bed height was 3 in. which corresponds to a loss of 3.5%; less than the specified 5.5%. The record of bed measurements appears in the Appendix.

Data Collection

Furnace operating data was taken at hourly intervals and recorded in log sheets which appear in the Appendix.

Sampling and Analyses

Composite samples of furnace feed carbon and furnace product carbon were made by placing approximately 6 oz. into a quart container every 2 hours. Every 8 hours a composite was completed. These samples were analyzed by Ultrachem Corporation of Walnut Creek, California for apparent density, iodine number and sieve analysis. The procedures used were those appearing in the U.S. EPA Process Design Manual for Carbon Adsorption.

A sample of the carbon transported from the adsorber to the regeneration area was analyzed for grease content. The value determined equates to approximately 0.2% by weight.

Regeneration efficiency was monitored during the test by frequent analyses of apparent density and some iodine number determinations. These analyses were mainly conducted by Mr. Lou Billello of ICI. Adjustments in furnace shaft speed and steam rate were made based on these analytical results.

APPENDIX III.

ACTIVATED CARBON ANALYTICAL RESULTS

November 30, 1978

B.S.P. Envirotech
One Davis Drive
Belmont, CA 94002

Attention: Mr. Ivan Joya

Report #17473-revised Vallejo Job #5041-21

Subject: Analysis of activated carbon.

Samples Submitted: On November 20, 1978, we received twelve activated carbon samples for apparent density, sieve analysis and iodine number. We also received one activated carbon water sample in a 300 mL glass jar for grease analysis. It was requested that all samples be analyzed on a "rush" basis.

The activated carbon samples were hand labeled: "BSP Vallejo 8 hr Composite" and were distinguished by the following labeling:

UC#	Date	Time	Sample type
1	11-15-78	1200-1800	MHF Feed
2	11-15-78	1200-1800	MHF Product
3	11-15-78	2200-0400	MHF Feed
4	11-15-78	2200-0400	MHF Product
5	11-16-78	0600-1200	MHF Feed
6	11-16-78	0600-1200	MHF Product
7	11-16-78	1600-2200	MHF Feed
8	11-16-78	1600-2200	MHF Product
9	11-17-78	0000-0600	MHF Feed
10	11-17-78	0000-0600	MHF Product
11	11-17-78	0800-End	MHF Feed
12	11-17-78	0800-End	MHF Product
13	BSP Vallejo 2030 11-16 Sample from Bed Eductor, Grease		

Procedures: Procedures followed for activated carbon sample analyses were supplied by Mr. Ivan Joya to Ultrachem.

Note: Per telephone conversation of November 21, 1978, with Mr. Vic Feudale the procedure for sieve analysis was modified to extend shaker time to a total of five minutes instead of the recommended three minutes.

All activated carbon samples were dried at 140°C for one hour preceeding analysis.

Sample from bed educator was analyzed for grease. The jar contained approximately 250 mLs; 90% water and 10% activated carbon. The water portion was extracted with freon in a separatory funnel and the charcoal portion was extracted with hexane using a sohxlet extraction.

UC #	Apparent Density gm/cc	Iodine Number	Sieve Analysis Wt % Retained on Screen #12	#14	#20	#30	#40	Pan
1	0.453	331	0.09	0.70	45.1	49.1	3.53	1.51
2	0.404	624	0.20	1.46	62.3	33.7	1.94	0.47
3	0.439	403	0.13	0.66	44.2	47.5	5.04	2.47
4	0.389	650	0.24	1.19	51.7	42.7	3.41	0.77
5	0.442	438	0.08	0.60	41.3	51.1	4.71	2.22
6	0.414	627	0.12	0.72	45.8	47.2	5.06	1.13
7	0.436	516	0.24	1.21	47.9	44.7	4.20	1.74
8	0.402	619	0.10	0.69	39.7	48.2	6.92	4.31
9	0.442	525	0.17	1.01	43.6	47.1	5.83	2.25
10	0.412	645	0.12	1.04	45.6	46.4	5.35	1.52
11	0.433	492	0.22	1.00	41.2	48.0	6.61	2.95
12	0.399	639	0.16	0.93	43.2	46.6	6.42	2.72

Results:

1. Sample from Eductor (#13)

	mg grease
Aqueous portion (freon extractable)	1.7
Charcoal portion (hexane extractable)	19.2
Total mg	20.9

CASE HISTORY NO. 6

ORANGE COUNTY WATER DISTRICT
FOUNTAIN VALLEY, CALIFORNIA
MUNICIPAL WASTEWATER RECLAMATION AND GROUNDWATER RECHARGE

HISTORY AND INTRODUCTION

Water Factory 21 is the AWT plant operated by the Orange County Water District as part of their groundwater injection project. The plant has been designed to improve the quality of secondary effluent by providing lime treatment, air stripping, recarbonation, chlorination for algae control, filtration, granular activated carbon adsorption (GAC), reverse osmosis, and final chlorination for disinfection and ammonia removal. A schematic of the basic process train is given in Figure A-12.

DESIGN DATA

Carbon Columns

Flow	15 mgd (influent to plant is secondary effluent)
GAC columns	(see Figure A-13)
Number	Seventeen
Size	12-ft diameter; 41-ft height; 24-ft sidewall height; conical top and bottom
Empty bed contact time	34 min
Surface loading	5.9 gpm/ft^2
Flow	Originally upflow countercurrent changed to downflow to reduce escape of carbon fines
Carbon	Filtrasorb 300 8 x 30 mesh; 26 lb/ft^3 bulk density; 38 tons/column

GAC Reactivation System (Figure A-14)

The carbon reactivation process follows several basic steps:

1. Exhausted carbon extracted from column as slurry is transferred to dewatering bins.

2. Carbon is drained for 10 min.

3. Moist carbon is transferred by stainless steel screw conveyor to top of furnace.

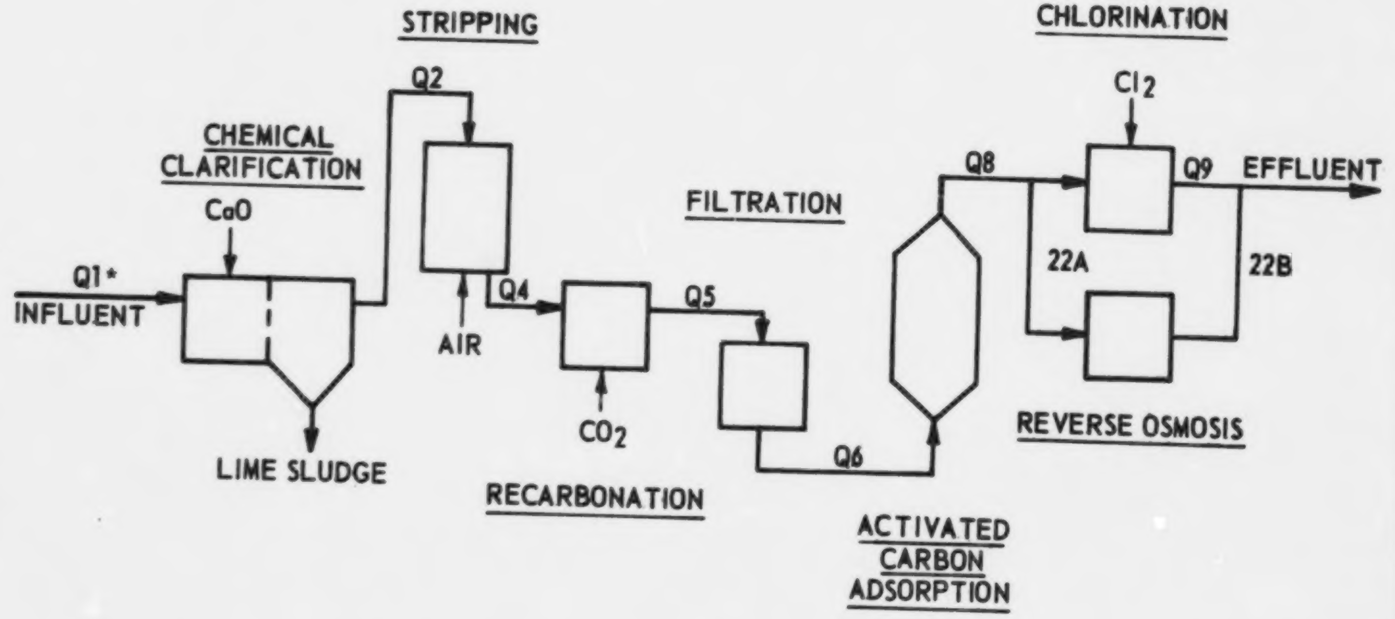
STRIPPING
CHLORINATION
Q2
Cl_2
CHEMICAL CLARIFICATION
CaO
Q8
Q9
EFFLUENT
FILTRATION
Q1*
INFLUENT
Q4
Q5
22A
22B
AIR
CO_2
Q6
REVERSE OSMOSIS
LIME SLUDGE
RECARBONATION
ACTIVATED CARBON ADSORPTION

Figure A-12. Schematic diagram of 15 mgd (3 mgd reverse osmosis) advanced water reclamation plant, Orange County Water District, CA. (*Denotes sampling point.)

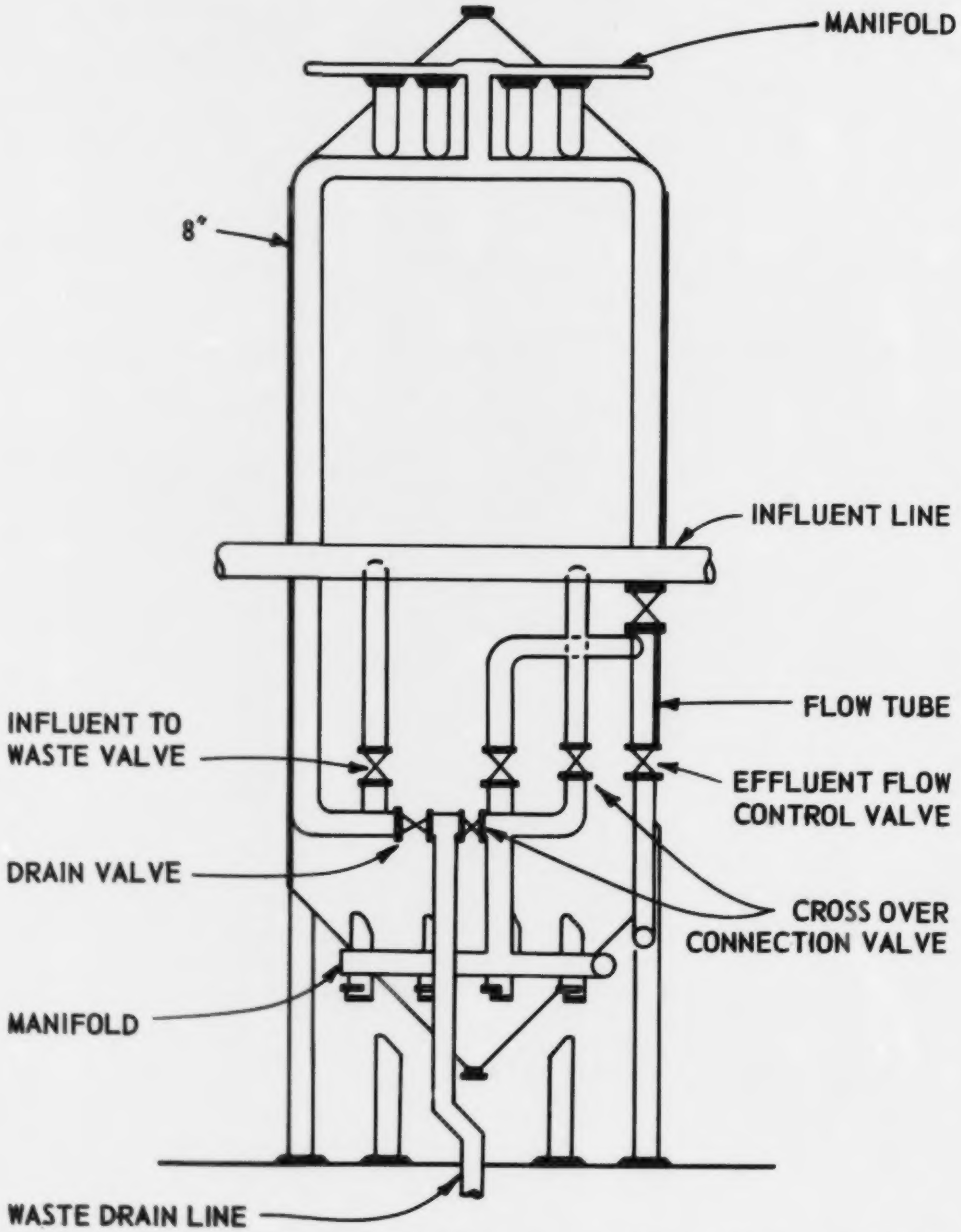
MANIFOLD
8"
INFLUENT LINE
FLOW TUBE
INFLUENT TO WASTE VALVE
EFFLUENT FLOW CONTROL VALVE
DRAIN VALVE
CROSS OVER CONNECTION VALVE
MANIFOLD
WASTE DRAIN LINE

Figure A-13. Schematic diagram of granular activated carbon contactor vessels, Orange County Water District, CA.

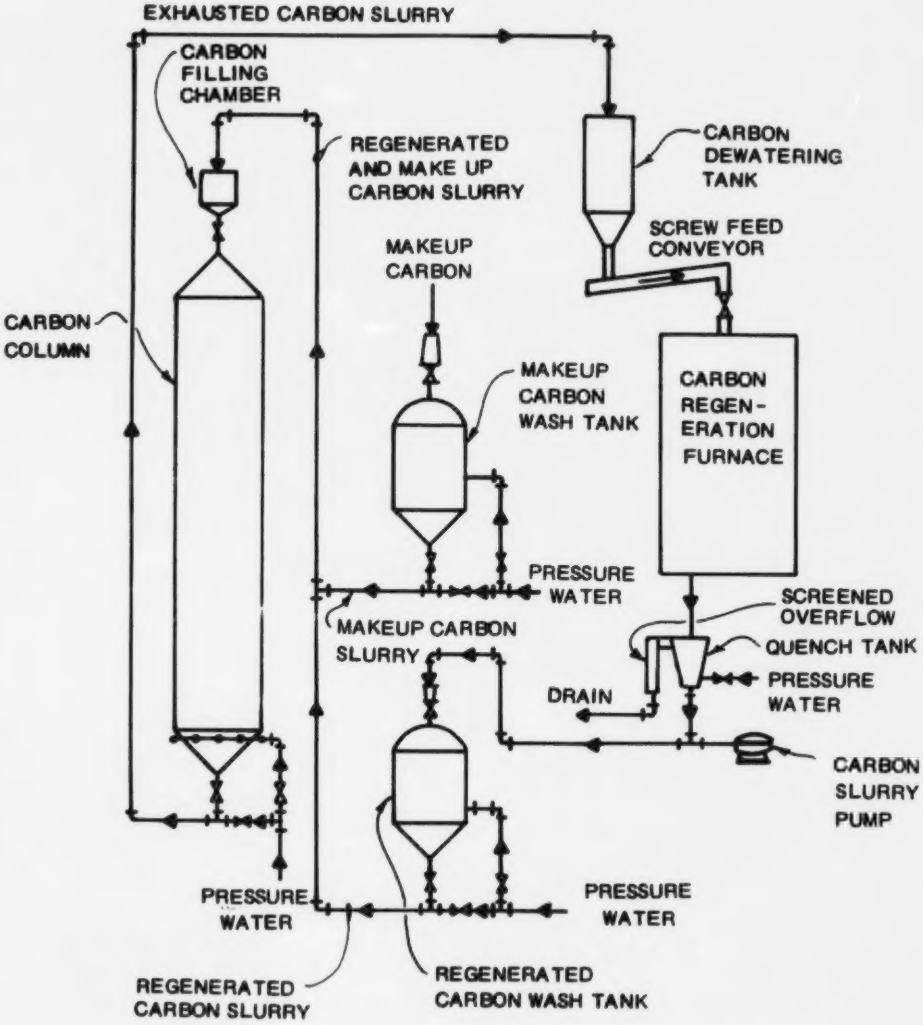
EXHAUSTED CARBON SLURRY
CARBON FILLING CHAMBER
REGENERATED AND MAKE UP CARBON SLURRY
CARBON DEWATERING TANK
SCREW FEED CONVEYOR
MAKEUP CARBON
CARBON COLUMN
MAKEUP CARBON WASH TANK
CARBON REGEN-ERATION FURNACE
PRESSURE WATER
SCREENED OVERFLOW
MAKEUP CARBON SLURRY
QUENCH TANK
PRESSURE WATER
DRAIN
CARBON SLURRY PUMP
PRESSURE WATER
PRESSURE WATER
REGENERATED CARBON SLURRY
REGENERATED CARBON WASH TANK

Figure A-14. Carbon regeneration system, Orange County Water District, CA.

4. Carbon moves through furnace with the aid of four stainless steel rabble arms on each hearth.

5. Regenerated carbon is cooled in a quench tank and pumped to a de-fining chamber.

6. De-fined carbon is returned to GAC adsorbers for reuse.

The reactivation furnace has the following characteristics:

Type	Six-hearth, gas fired
Rated capacity	Six tons dry carbon/day
Temperature	1700°F
Afterburner	To combust volatilized organics
Venturi wet-scrubber	To remove carbon fines from furnace exhaust

CARBON SYSTEM PERFORMANCE

Between January 1976 and January 1979, there were three distinct operating periods for Water Factory 21:

- 1/76 to 10/76 - Trickling filter influent, no breakpoint chlorination, no reverse osmosis, no injection
- 10/76 to 3/78 - Trickling filter influent, breakpoint chlorination, no reverse osmosis, injection
- 3/78 to 1/79 - Activated sludge influent, no forced air circulation in stripping, partial ammonia removal by chlorination, reverse osmosis, injection

During the second and third periods, the GAC columns were effective in removing COD and TOC from the flow. During period two, the COD was reduced by 60 percent and the TOC by 51 percent. About 14 percent of the GAC in each column was regenerated every 40 to 70 days during this time. In period three, the COD removal was 49 percent and 50 percent of the column carbon was regenerated every 6 months. Trace organics and heavy metals were removed to various degrees during these two test periods.

Figure A-15 illustrates the effect of carbon regeneration on COD removals. The change in influent to the plant from trickling filter effluent to activated sludge effluent significantly reduced the COD loading to the carbon columns and also reduced the frequency of regeneration.

Test results showed that trihalomethanes (THM) are removed much more effectively with fresh GAC than with old GAC. Also, the more highly brominated THM are removed more efficiently than chloroform. The biggest problem in assessing the results of the THM testing was the lack of sufficient analytical precision when concentrations are near the detection limit.

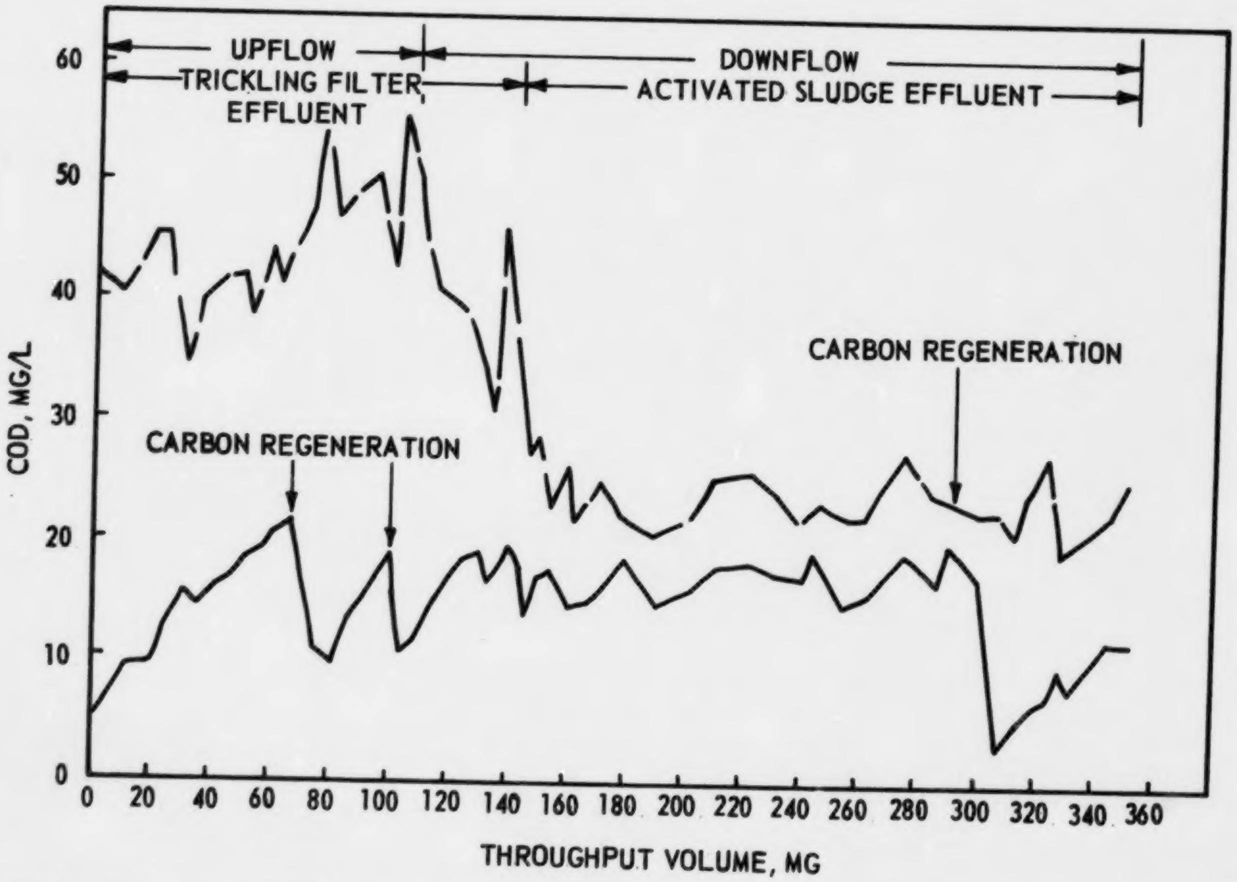

Figure A-15. Influent and effluent COD for a typical GAC column during the latter part of Period 2 and into Period 3.

CAPITAL AND OPERATION AND MAINTENANCE COSTS

Capital Costs

The capital costs for the GAC system at Water Factory 21 totalled $3.3 million in 1972. These costs include sitework, landscaping, electrical and yard piping, but not land. The breakdown of the costs is as follows:

Adsorption	$1,432,000
Furnace	489,000
Building, controls, etc.	1,386,000
	$3,307,000

OPERATION AND MAINTENANCE COSTS

The unit costs of operating the GAC system at Water Factory 21 from July 1, 1978, through June 30, 1979, are presented in Table A-13. The total quantity of effluent treated was 3,991.4 mil gal, the total quantity of carbon processed was 694 tons, and the total make-up carbon was 40 tons.

TABLE A-13. ANNUAL OPERATION AND MAINTENANCE COSTS FOR THE GAC SYSTEM AT WATER FACTORY 21 (1978/79)

	Cost, $/mil gal
Adsorption	
Operations labor, administration, and engineering	$ 6.26
Maintenance labor	8.76
Electricity	10.78
Maintenance materials, tools, etc.	4.00
Subtotal	29.80
Amortized capital	55.43
Total	$ 85.23
Reactivation	
Operations labor	$ 25.05
Maintenance labor	8.75
Electricity	3.59
Gas	4.65
GAC make-up	12.02
Maintenance materials	6.63
Subtotal	60.69
Amortized capital	20.55
Total	$ 81.24
Total for GAC system	$166.47

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David Argo, personal communication, August, 1979.

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CASE HISTORY NO. 7
CITY OF NIAGARA FALLS, NEW YORK
MUNICIPAL WASTEWATER TREATMENT

HISTORY AND INTRODUCTION

Niagara Falls' first municipal wastewater treatment plant was completed in 1939. In 1940, the plant was treating an average dry weather flow of 62 mgd. A series of intercepting sewers were built at the same time to collect domestic and industrial wastes and convey them to the treatment plant. A diversion sewer was built to collect unpolluted cooling water from industries in the Buffalo Avenue industrial complex and discharge it through the Adams Generating Plant Tailrace Tunnel to the river just upstream of the Rainbow Bridge.

This system served the needs of the City and industry until the early 1960's when concern about the adequacy of the sewerage system was expressed. In 1964, final plans were completed for upgrading the tnen existing plant at Ashland Avenue to provide primary treatment. These plans were abandoned when new state and federal anti-pollution regulations required a minimum of secondary treatment. Further progress on the improvement of the City's wastewater facilities was delayed during preparation of comprehensive sewerage studies, which were undertaken for all of Niagara County and for several municipalities in the Niagara Falls area.

In early 1970, a large environmental engineering firm was retained to make a preliminary study, prepare final designs, provide services during construction, and assist during start-up of new municipal wastewater treatment facilities. Analyses indicated that extensive pilot plant studies were required to select a treatment methodology. Although the City had to provide the equivalent of secondary treatment to comply with international, federal, and state effluent regulations, the large volume of highly toxic waste generated by local industries precluded use of conventional biological treatment processes.

A 1971 report, based on several months of pilot testing, recommended construction of a plant incorporating physical-chemical treatment of the combined industrial and municipal wastes. The City and regulatory agencies accepted the report and subsequently gave the go-ahead to prepare final plans for a 48 mgd AWT plant and a number of collection system improvements, such as a 2-mile long, 6-ft diameter, concrete-lined rock tunnel intercepting sewer; a 20 mgd wastewater pumping station located on the old plant site; force main and gravityflow conduit to the new treatment plant on Buffalo Avenue; and connections to convey 29 mgd of industrial waste and 19 mgd of municipal wastes and estraneous flow to the interceptor system.

Construction on the system improvements and the treatment plant began in 1973. The site of the wastewater treatment plant was originally developed between 1890 and 1904 as the Adams Generating Plant. Construction of the improvements was essentially completed in 1977, and flow was pumped to the treatment processes in mid-April 1977. The treatment plant is located on a 22.6-acre site about a mile above the celebrated Niagara Falls in the southwestern section of the City.

The cooperative spirit between industry and the City of Niagara Falls made the improvements possible; 18 of the larger industries provided the local share of construction costs. These industries, through the Industrial Liaison Committee, provide valuable guidance and support in regulating the quality of the sewage received at the wastewater treatment plant. In addition, the technical expertise and financial help of the state and federal pollution control agencies made the project a successful reality. Niagara Falls is proud of this spirit and considers it an integral part of the areawide wastewater treatment system mandated by the Water Pollution Control Act Amendments of 1972.

DESIGN DATA

The Niagara Falls Wastewater Treatment Plant is a physical-chemical plant that incorporates trash removal, chemical addition, rapid mixing, flocculation, sedimentation, acid addition and mixing, GAC content in downflow filters, and chlorination (Figure A-16).

Basic design data for the plant are given in Table A-14.

TABLE A-14. BASIC DESIGN DATA, NIAGARA FALLS AWT PLANT

Constituent	1970	1990	2020
Population served	86,000	114,000	132,000
Design wastewater flows			
Average mgd	-	48	48
Peak mgd	-	85	85

Key system units	Number of units
Flocculation basins (60 ft x 60 ft x 12 ft)	5
Sedimentation basins (250 ft x 60 ft x 12 ft)	5
Activated carbon contact beds (17 ft 4 in. x 42 ft with carbon depth 8 ft 9 in.)	28
Chlorine contact tanks (120 ft x 40 ft x 15 ft)	2
Outlet to lower Niagara River (18 ft x 21 ft x 7,000 ft)	1
Sludge thickening basins (70 ft in diameter)	2
Sludge vacuum filters (11 ft 6 in. in diameter drum x 14 ft wide)	4
Carbon regeneration furnace (14 ft 3 in. in diameter)	1

Basis of GAC System Design

The GAC contactors are rectangular, open-top, downflow beds of reinforced concrete construction. There are 28 beds each 17 ft, 4 in. by 42 ft with an 8 ft, 9 in. depth of GAC. The filter underdrains originally consisted of a false

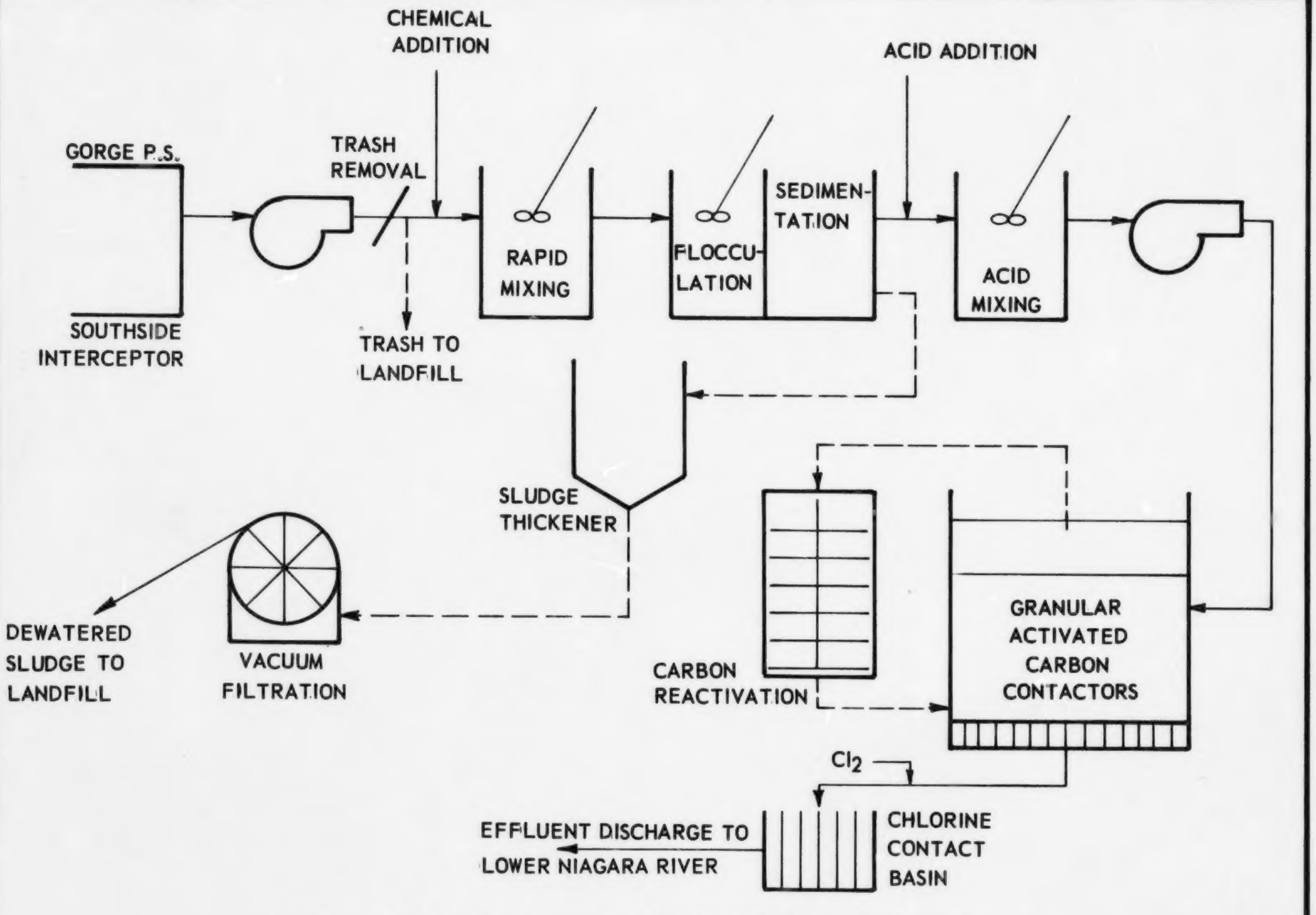
CHEMICAL ADDITION
ACID ADDITION
GORGE P.S.
TRASH REMOVAL
RAPID MIXING
FLOCCU-LATION
SEDIMEN-TATION
ACID MIXING
SOUTHSIDE INTERCEPTOR
TRASH TO LANDFILL
SLUDGE THICKENER
DEWATERED SLUDGE TO LANDFILL
VACUUM FILTRATION
CARBON REACTIVATION
GRANULAR ACTIVATED CARBON CONTACTORS
Cl2
EFFLUENT DISCHARGE TO LOWER NIAGARA RIVER
CHLORINE CONTACT BASIN

Figure A-16. Process flow schematic, Niagara Falls, NY.

bottom made up of concrete panel plates fitted with plastic nozzles located above a plenum. At design flow, 40 min contact time is provided with the carbon. The surface flow rate is 1.67 gpm/ft^3. Air-hydraulic backwash is provided for cleaning the beds.

Carbon is transferred in water slurry using hydraulic eductors. Makeup, spent, and regenerated carbon is stored, each in separate cone-bottomed vessels. Within each carbon bed, just above the filter bottom, a pressure water header with water jet nozzles assists in removing the bed of carbon from the flat bottomed beds.

Carbon is thermally reactivated in a single 14-ft 3-in. diameter, 6-hearth furnace equipped with an afterburner and a wet scrubber. Spent carbon is dewatered and conveyed into the furnace by an inclined screw.

CARBON SYSTEM PERFORMANCE

In early 1978, during the few months that the GAC system operated, the quality of the plant effluent was basically as anticipated and all discharge requirements were met.

By mid-1978, however, operation of the carbon system was shutdown because of mechanical failure rather than any process problem.

When the treatment plant was first started in April 1977, intolerable amounts of chlorine and chlorine components were being discharged into the sewer system from industrial wastes, resulting in equipment damage, hazard to personnel, and possible loss of carbon by chlorine oxidation. The carbon beds, which had to be bypassed during this period, were not started up on a limited flow basis until January 1978. The flow to the beds had to be limited because of the then extremely high pH in the plant influent, rapidly changing pH, and requirements for large quantities of sulfuric acid to reduce the alkalinity. The carbon operation had to be shut down for the entire month of March 1979, but began operation again in April of that year.

In early summer, the plant experienced a rupture of several carbon bed bottoms and, after the carbon was removed, extensive corrosion and damage to the precast filter bottoms and gullet wall projections were discovered. As a result, the operation of the carbon filter beds was suspended, and the plant has been providing primary treatment to the wastewaters flowing to it since that time.

The filter bottoms consist of a grid of 3-in. thick x 2-ft square precast concrete panels, each holding nine plastic nozzles screwed into inserts; the panels are supported on 9-in. diameter by 3-ft high concrete columns at each corner. These panels were cast with a V-groove around all four edges. The hold-down system consists of four No. 3 reinforcing bars projecting from the support piers, field-bent, to lie along the V-groove panel edges, and the space between panels is packed with no-slump cement mortar to lock the panels and reinforcing together.

Analysis of the filter bottom design indicates that the system (columns, reinforcement, and precast panels) is adequate to sustain the gravity loads and the uplift loads due to the normal expected variations in the backwash flow and operating pressures, normal impact forces, or those forces expected when some nozzles need cleaning.

Examination of the ruptured panels, carbon transport gullet wall, and exposed hold-down reinforcing bars showed extensive corrosion buildup on the reinforcing bars, somewhat aged cracked seams in the grout, and some aged cracks along the failure plane of the panels. In addition, severe corrosion buildup was observed on the air and spray piping brackets and supports.

It is apparent that extraordinarily strong wastewaters in the backwash system penetrated cracks or voids in the cement mortar joint and severely attacked the reinforcing rods creating a substantial corrosion buildup.

Observations of the damaged areas indicate two conditions caused the rupture. The first was the expansion of the assembly, causing the plates to bundle or the gullet wall projection to shear. The second condition causing rupture was a vertical upward pressure causing precast panels to move upward at the support columns. The probable cause for the first condition is the corrosion of the reinforcing bars in the panel joints, causing an expansion of the diameter of the reinforcing bar and imparting a horizontal thrust on the plates. A probable cause of rupture for the second condition is pressure beneath the plates causing rupture at the panel joints. With a structurally weakened panel, as described above, it required only a small amount of net upward overpressure to cause rupture.

Failure by uplift could have been the final act of a condition created in another manner. The corrosion of the reinforcing may have imparted a thrust in the plates and caused a horizontal crack to develop. The weakened plate would then rupture by uplift pressures within the normal backwash range. In summary, where definite evidence was found that the horizontal thrust alone caused individual ruptures and that uplift pressures during normal operation resulted in ruptures, it was not possible to find positive evidence that uplift pressures, by themselves, were the cause. This indicates that a major problem in the filter bottom was corrosion of the reinforcing steel in the precast panel joints.

Evaluation of corrective measures includes modifying the anchorage assemblies and modifying the concrete bottom inself including placing new all-fiberglass reinforcing plastic filter bottoms in the filters, and placing overpressure relief vent riser pipes in each bed. In addition, positively to prevent future back-up of strong primary settled effluent from the chlorine contact chamber, a flap gate is to be installed at the chlorine contact chamber end of the filter effluent pipe.

The restoration program will include design modifications to allow backwash of the beds as two distinct units; this will eliminate the possibility of all components failing simultaneously with the resultant loss of the whole system of beds.

The carbon beds need rehabilitation to provide increased reliability and maintainability features after difficulty with the six beds in mid-1978 and the consequent need to remedy all 28 beds similarly constructed. Piping changes will provide additional operational flexibility.

The rehabilitation project (at an estimated $3.1 million) includes providing and installing temporary piping changes in the carbon-transfer piping systems, transferring GAC from and returning it to the carbon-filter beds; removing carbon filter bed nozzles and plates; furnishing and installing new filter-bottom panels and nozzles; changing the filter-bottom panel supporting masonry; cleaning all spaces into which GAC or other contaminating matter has penetrated because of the rupture of filter beds; providing and installing new supports of air wash piping and spray water piping in the beds; changing piping and repairing and adjusting butterfly valves in the backwash water piping, and providing and installing backwater flap gate.

CAPITAL AND OPERATION AND MAINTENANCE COSTS

The total construction cost of the plant was $61 million. Local, state, and federal cost participation was $8.91 million for the City of Niagara Falls; $7.47 million for the New York State Department of Environmental Conservation Grant, and $44.82 million for the EPA ($61 million total).

Costs for operation and maintenance under normal conditions are not available at this time.

CASE HISTORY NO. 8
CITY OF FITCHBURG, MASSACHUSETTS
INDUSTRIAL & MUNICIPAL WASTEWATER TREATMENT

HISTORY AND INTRODUCTION

In 1968, a plan for domestic and industrial wastewater disposal was prepared for the City of Fitchburg, Massachusetts. It outlined pollution abatement facilities for the City and its industries. An 11-mgd, two-stage activated sludge treatment plant was proposed for handling the municipal wastewaters from East Fitchburg and several of its industries. The industrial wastewaters from the Weyerhaeuser Co., Paper Division, the Fitchburg Paper Co., and the Town of Westminster were to be treated in a second, 15-mgd conventional activated sludge treatment plant.

In the spring of 1970, pilot plant studies were conducted to determine the efficiency of using a physical-chemical means to treat the wastes in the second plant. Treatment included coagulation, flocculation, and sedimentation of the wastewaters followed by treatment in activated carbon columns. Waste loadings from the two mills and town amount to approximately 46,000 lb/day of suspended solids and 8,000 lb/day of BOD. The sedimentation basins removed about 95 percent of the suspended solids and about 40 to 50 percent of the BOD.

The pilot studies indicated the effectiveness of the coagulation, sedimentation, activated carbon system to produce an effluent of superior quality that at least one of the paper companies wanted to recycle for reuse in its operations. Full-scale design of the West Fitchburg treatment facility was completed in July 1971; construction of the Fitchburg plant was completed in 1975. Since that time, the plant has operated intermittently because of a variety of mechanical problems, rather than because of any process problems with GAC adsorption or regeneration. It appears that these mechanical problems will be solved and corrected so that the plant can be in full operation on a continuous basis about October 1979.

In the 1968 report, the paper companies had requested treatment for more than 20 mgd of their wastewaters; since that time they have reduced their requirements by about 30 percent. The study recommended that a biological treatment facility be constructed for West Fitchburg. The plant was to have facilities for coagulation, flocculation, and sedimentation, which would precede the proposed activated sludge process.

Later studies conducted in 1968 and 1970 indicated that with proper pH control and the use of sodium aluminate and certain polyelectrolytes, the "primary" system would effectively remove 90 to 95 percent of the suspended solids and approximately 50 percent of the BOD in the wastewater. Because loadings to the activated sludge system would be about 35 to 40 mg/L of BOD lower than originally anticipated--alternative methods of wastewater treatment were studied. The activated carbon process was considered, and a decision was made to run a pilot plant study.

GAC Pilot Plant Study

Isotherm studies of the wastewaters indicated that approximately 2.6 lb carbon/1000 gal would be required to treat the wastewaters and that the isotherm was approximately linear. Other investigations, however, showed poor correlation between the isotherm results and exhaustion rates in column tests.

A pilot plant facility (Figure A-17) was, therefore, established at the Weyerhaeuser Co., Paper Division, where waste was available from one of the primary clarifiers. The Fitchburg Paper Co. daily trucked its wastewaters in 55-gal drums to the pilot plant facility. The laboratory work for the pilot plant was done at the existing Fitchburg wastewater treatment plant's laboratory facilities.

Wastewaters from the Weyerhaeuser clarifier and Fitchburg Paper Co. were settled in a tank truck and then pumped at a rate of approximately 0.35 gpm to the adjacent columns. Four columns were used with 9.2, 11.3, 16.0, and 16.0 lb of GAC, respectively, and empty column contact times of 5.8, 7.2, 9.9, and 9.9 min, respectively.

The results of the pilot plant study were used to design the full-scale carbon adsorption system. The system is based on an average daily flow of 15 mgd and requires 1600 lb carbon/mil gal waste treated. This represents approximately 2.1 times the carbon needed for an equivalent level of treatment for settled domestic sewage.

A thorough economic analysis was made of the activated carbon system as an alternative to the activated sludge process. Because the cost associated with the primary treatment portion of the alternative facilities were assumed to be similar, they were not considered. Although the activated carbon system proved to be approximately 6 percent more expensive than the activated sludge system, the flexibility afforded the City in the operation of the facility more than outweighed the additional capital cost.

A request for a change in the process from activated sludge to activated carbon (made to the Massachusetts Division of Water Pollution Control in 1970) was granted. All parties concerned agreed that the activated carbon plant would produce a better quality effluent than would the activated sludge facility; primarily because a better and more consistent removal of BOD and COD could be achieved and because it would remove the color from the wastewater better than would have been possible from the activated sludge plant. The plant would also be less prone to upsets caused by the highly variable loads and would be capable of being shut down or run at far less than full capacity--for example, to treat the municipal wastes only.

In addition, one of the paper companies requested that, should the company desire, water from the treatment facility would be made available to it for recycling in its process. The unique location of the mills on the river means that the Fitchburg Paper Co. uses effluent from the Weyerhaeuser Co. for its

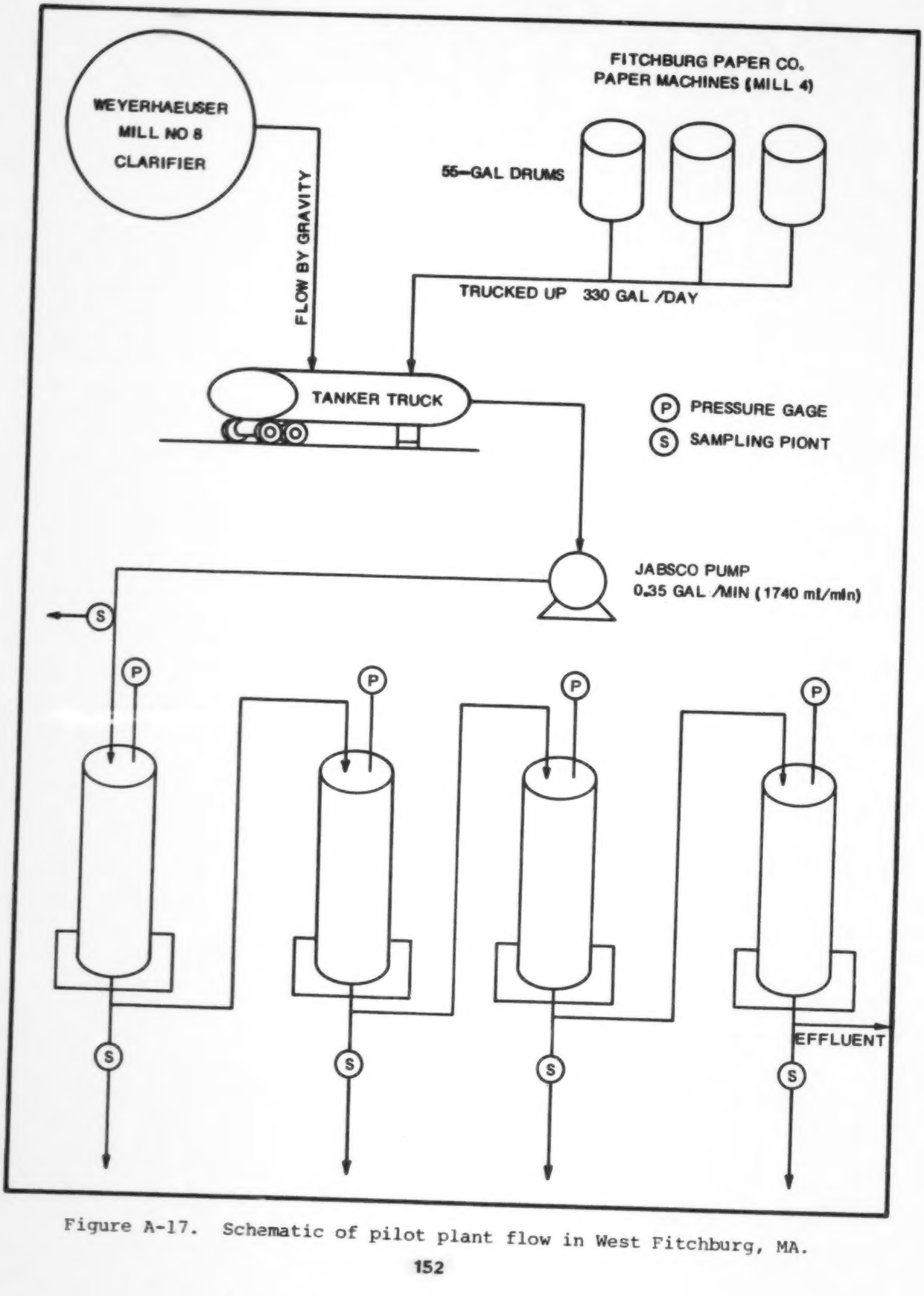
WEYERHAEUSER
MILL NO 8
CLARIFIER
FLOW BY GRAVITY
FITCHBURG PAPER CO.
PAPER MACHINES (MILL 4)
55-GAL DRUMS
TRUCKED UP 330 GAL /DAY
TANKER TRUCK
P PRESSURE GAGE
S SAMPLING PIONT
JABSCO PUMP
0.35 GAL /MIN (1740 ml/min)
S
P
P
P
P
EFFLUENT
S
S
S
S

Figure A-17. Schematic of pilot plant flow in West Fitchburg, MA.

process water. The Fitchburg Paper Co. also uses the effluent from the treatment plant after it flows into the river, which could just as easily be transported directly to the company for reuse.

DESIGN CRITERIA AND SYSTEM OPERATION

The processes required at the West Fitchburg wastewater treatment plant are shown in Figure A-18. Effluent from the coagulation-flocculation-sedimentation system is pumped to the carbon filters.

Maximum pumping capacity of each of the four units is 8,500 gpm at a design head of approximately 145 ft. The pumps and wet well have been designed to allow for a potential 10-ft headloss through prefiltration facilities should they be deemed necessary due to rapid filter plugging.

Twelve carbon filters, each 20 ft in diameter with a 15.5-ft bed depth, are provided for parallel operation. The filters and piping allow for two vessels to be out of operation, one for backwashing and the other for regeneration. Ten active vessels permit maximum utilization of the carbon. The surface loading and empty bed contact time for the 10 active vessels is about 8 gpm/ft^2 and 15 min, respectively, at peak hourly flow. The flow through the vessels is divided uniformly and controlled by individual rate controllers. The vessels have been designed to operate at a maximum pressure of 50 psi. The overall vessel height from dished end to dished end is approximately 33 ft, which allows for a 40 percent expansion of the carbon bed on backwashing. The filter bottom consists of 1 ft of gravel over Leopold tiles.

The filters are backwashed with plant effluent using two variable speed, vertical, mixed-flow or vertical turbine pumps, one of which serves as a standby. A maximum wash water rate of 9,100 gpm ensures 40 percent expansion of the filter at 75°F, and the water is discharged to a backwash lagoon. Each filter is washed for 15 min daily, with one filter backwashed every 2 hr on a time cycle; a surface wash is also used. A clear well with a volume equal to approximately 10 times a single backwash is provided, but the effective volume is greater since there is a continuous flow into the clear well at all times except at shutdown. A backwash basin (two, 65-ft diameter tanks) is provided to uniformly return the backwash water together with the carbon transfer motive water to the head end of the plant. Under the most adverse conditions, the maximum rate of return to the head end of the plant is 2.2 mgd or about 12 percent of the plant throughout. Because the oxygen is depleted from the filtrate, the effluent is aerated to maintain a level of 5 mg/L of dissolved oxygen.

Approximately once a week it is necessary to replace the carbon in one of the vessels. Spent carbon is transferred to a spent carbon storage vessel through water eductors, which are sized to empty or refill one vessel in less than 6 hr. The volume of the spent carbon and regenerated carbon storage vessels is equal to two times the carbon in any one filter vessel. The carbon is regenerated in a multiple-hearth furnace using steam that has been sized based on continuous operation with a loading rate of 100 lb carbon/day/ft^2 of hearth.

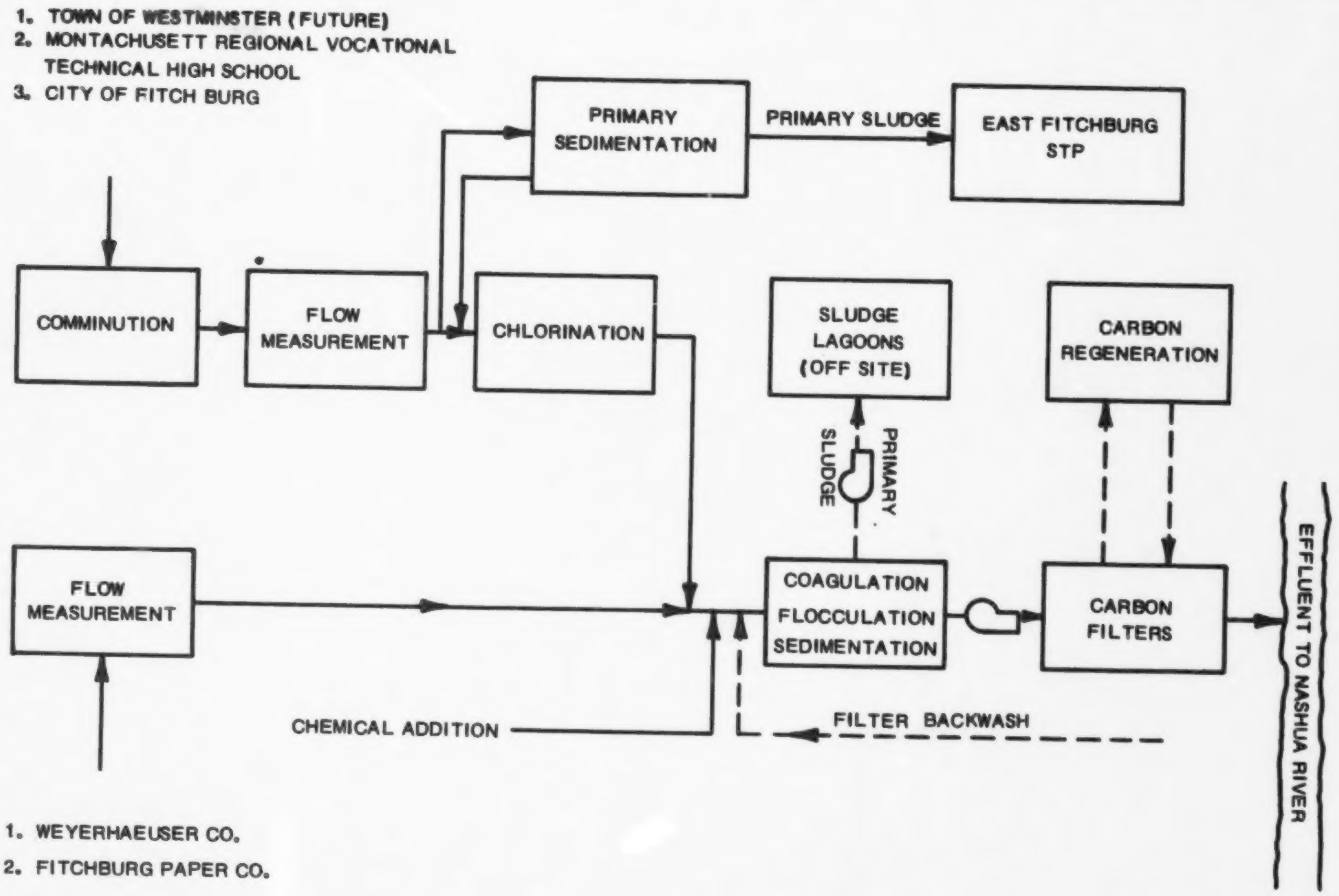
1. TOWN OF WESTMINSTER (FUTURE)
2. MONTACHUSETT REGIONAL VOCATIONAL TECHNICAL HIGH SCHOOL
3. CITY OF FITCH BURG
PRIMARY SEDIMENTATION
PRIMARY SLUDGE
EAST FITCHBURG STP
COMMINUTION
FLOW MEASUREMENT
CHLORINATION
SLUDGE LAGOONS (OFF SITE)
PRIMARY SLUDGE
CARBON REGENERATION
FLOW MEASUREMENT
COAGULATION FLOCCULATION SEDIMENTATION
CARBON FILTERS
EFFLUENT TO NASHUA RIVER
CHEMICAL ADDITION
FILTER BACKWASH
1. WEYERHAEUSER CO.
2. FITCHBURG PAPER CO.

Figure A-18. Schematic of flow, wastewater treatment plant, West Fitchburg, MA.

In transferring the carbon, two water streams are required: fluidizing water for maintaining the carbon-to-water ratio (1 to 2 lb carbon/gal slurry) and motive water to operate the eductors. Fluidizing water is pumped against essentially the static head and motive water at the most efficient combination of pressure and volume. Fluidizing water and motive water to and from the filter vessels is provided by separate, constant speed pumps that operate at 100 psi with suction from the process water header.

Operational Problems

A number of mechanical problems with the plant have been corrected:

1. Removal of pressure discharges from a gravity drain line beneath the plant floor.
2. Synchronization of filter influent plant flows.
3. Replacement of basin sludge pumps.
4. Modification of the filter flow control system.
5. Control of a corrosion problem in the plant water supply system.

There are three other problems well on the road to correction:

1. Odor control of the reaeration process.
2. Deterioration of carbon column linings.
3. Failure of carbon column surface wash systems.

The plant has been through one complete carbon reactivation cycle.

CARBON SYSTEM PERFORMANCE

Only a very limited amount of data have been generated by the carbon system to date because plant operation has been interrupted for prolonged periods of time to correct mechanical defects. The adsorbers are producing an effluent with a BOD concentration in the range of 20 to 30 mg/L. Waste discharge requirements are 8 mg/L of BOD. The reactivation process has performed much as expected.

The data collected in the pilot plant studies are summarized in Table A-15.

The resulting BOD and COD removals show that in Column 1 the average removal of BOD and COD was about 45 percent whereas in Column 3, after 23 min of contact time, almost 90 percent of the BOD and COD was removed from the wastewater. The concentrations of the BOD and COD in the effluent stream after only 13 min of contact time were less than 2.6 and 11.9 mg/L, respectively. This is well below the requirements needed to meet stream standards. These test

TABLE A-15. OPERATING RESULTS OF BOD AND COD REMOVAL IN PILOT PLANT STUDY OF WEST FITCHBURG WASTEWATER TREATMENT FACILITY

Constituent	Raw	Columns No. 1	No. 2	No. 3
Average wastewater characteristics, mg/L				
BOD	13.2	7.6	2.6	1.7
COD	53.4	29.2	11.9	6.8
Average removal, %				
BOD	-	42.0	80.0	87.0
COD	-	45.0	78.0	87.0

results and similar results for the removal of suspended solids and headloss across the filters showed that GAC was a practical form of treatment. No extrapolation of the pilot plant was necessary to arrive at design parameter values for the treatment facility.

PRELIMINARY ESTIMATE OF CAPITAL AND OPERATING COSTS

The estimated costs of construction and operation for the proposed treatment facility have not been refined because the design was not complete at the time the estimates were made.

The total estimated capital cost for the complete West Fitchburg plant is detailed in Table A-16 and amounts to $12,270,000.

The annual operating costs for the plant, including the items outlined in Table A-17 will amount to about $515,000. Approximately 70 percent of the operating costs of the activated carbon system ($140,000 of the estimated operating expense) is associated with makeup carbon, assuming 5 percent of the exhausted carbon is replaced. A reduction in the raw organic discharge by the industries or an increase in the removal efficiency in the primary portion of the treatment plant will have a greater effect on the operating costs of the activated carbon system than it might have had on the activated sludge system.

The industries and the City of Fitchburg have negotiated contracts that will ensure that the capital and operating expenses of the facility are funded solely by the industries until such time as Westminster enters the plant.

TABLE A-16. ESTIMATED CONSTRUCTION COSTS FOR WEST FITCHBURG WASTEWATER TREATMENT FACILITY

Item	Estimated cost
Site work	$ 1,315,000
Filter building	6,835,000
Sludge and chemical pumping station	503,000
Municipal influent structure	32,000
Municipal clarifiers	95,000
Flocculation and rapid-mix tanks	387,000
Wastewater clarifiers	1,035,000
Backwash lagoons	85,000
Post-aeration basin	90,000
Yard piping and miscellaneous structures	628,000
Electrical	865,000
Miscellaneous	400,000
	$12,270,000

TABLE A-17. ESTIMATED FIRST YEAR OPERATING COSTS* FOR WEST FITCHBURG WASTEWATER TREATMENT FACILITY

Item	Estimated cost
Salaries	$ 110,000
Power and heat	115,000
Chemicals	
Lime	17,000
Polymer	48,000†
Hypochlorite	1,000¶
Alum	63,000§
Makeup carbon	102,000**
Sludge, lagoon cleaning	28,000
Lab supplies	1,000
Maintenance	30,000
Total	$ 515,000

*Based on expected initial loadings to plant.

†Based on dose of 1 mg/L; expected dose may be as low as 0.3 to 0.5 mg/L

¶Based on chlorination of municipal wastes only.

§Based on maximum dose required.

**Based on present loadings.

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CASE HISTORY NO. 9
ARCO PETROLUEM PRODUCTS COMPANY
WATSON REFINERY
CARSON, CALIFORNIA
INDUSTRIAL WASTEWATER TREATMENT

HISTORY AND INTRODUCTION

The Watson Refinery of the ARCO Petroleum Products Company is located at Carson, California, in Los Angeles County. It is adjacent to the Dominguez Channel, a nonnavigable lined tidal estuary that is used for stormwater runoff and discharges from industrial plants including refineries.

A 1968 study by the Los Angeles Regional Water Quality Control Board showed that the oxygen demand of industrial wastes entering the channel was depleting the oxygen in the channel. Consequently, a resolution was issued limiting all discharges to the Dominguez Channel (Table A-18).

TABLE A-18. DOMINGUEZ CHANNEL DISCHARGE LIMITS

Parameter	Limit
Temperature	140°F max
Sulfides	1.0 mg/L max
Floatable oil	No visible
Dissolved oil	75 mg/L
pH, range	6.5 to 10.5
Cyanides	Below toxic concentrations
COD	1,330 lb/day max
Settleable solids	1.0 cc/L max

Many of the Watson Refinery sewers are combined so that process wastes and stormwater runoff will be mixed during rainy periods. Because of the complexity of the sewer system, segregation of wastes was not considered feasible. Therefore, a scheme had to be developed that would provide for disposal of process wastes during dry weather and combined wastes during the rainy season.

To dispose of normal dry weather process wastes, the Refinery and the Los Angeles County Sanitation District agreed that the District would accept process wastes with a minimum amount of treatment. The specific sewer discharge limits established by the Los Angeles County Sanitation District are shown on Table A-19.

In addition (to the above limits) any compounds that give off strong odors (mercaptans) toxic or flammable gases are prohibited.

TABLE A-19. LOS ANGELES COUNTY SANITATION DISTRICT SEWER DISCHARGE LIMITS

Parameter	Limit
Temperature	120°F max
Sulfides	0.1 mg/L max
Floatable oil	10 mg/L max
Dissolved oil	25 mg/L max
pH	6.0 min
Cyanides	10 mg/L
Nitrates	5% max

Because of large volumes of stormwater runoff, the County would not accept any process wastes diluted with stormwater. Whenever rainfall amounts would exceed 0.1 in., all flow was required to be diverted from the Sanitation District sewers until 24-hr after the rain ceased. That requirement was later changed to a 4-hr wait.

To meet the discharge conditions established for both disposal points, it was decided to discharge the normal dry weather process flows to the Sanitation District sewer and to store all of the rainy season mixed wastewater (process and stormwater) in a large (50 mil gal) reservoir. The stored water would be treated to remove organics, which exert a COD, and the treated water would be discharged to the Dominguez Channel.

Several alternative methods for treating the impounded wastewater were considered including biological methods. Since treatment would only be required during wet weather however, these methods were considered too difficult to start-up and control on an intermittent basis. Also the desired 95% removal of COD would not be achieved by these methods.

Using activated carbon to adsorb the soluble COD producing compounds was the best treatment choice since it could be placed in operation quickly whenever it was needed, be readily controlled, and be adapted to changing feed conditions and discharge requirements as necessary.

To meet the discharge limitations and compliance schedule, it was necessary to have the treatment plant in operation by February, 1971, so that the maximum discharge of 1,330 lb/day total COD would not be exceeded.

DESIGN OF GAC SYSTEM

Bench and pilot scale tests were run to determine the feasibility of using GAC to reduce soluble COD and phenol concentrations to levels that would meet the discharge limits. Pilot plant tests were run using 5-in diameter Plexiglas columns with a total carbon depth of 13 ft. Runs were made using various feed COD concentrations and contact times. As a result of these tests, the following design criteria were established:

Flow rate	3,000 gpm
Influent COD (total)	150 mg/L average
Effluent COD (total)	37 mg/L average
Holding basin	50 mil gal capacity
Carbon dosage	1 lb/1,000 gal treated

In addition to the above, the plant was to be designed to run 90 days without replacing or regenerating the carbon if the maximum expected rainfall amounts were received. The spent carbon would be regenerated during the dry season thereby allowing for a regeneration furnace of minimum size.

Basis of GAC Design and Operation

The purpose of the activated carbon adsorption process is to remove soluble organic compounds, which exert an oxygen demand on the receiving body of water (Dominguez Channel), from the mixed process and stormwater. The discharge requirements limit the effluent total COD to 1,330 lb/day. The following design basis was established to meet that limit.

Activated Carbon Adsorption

Number of carbon columns	Twelve
Type	Downflow, gravity
Size of columns	12 ft x 12 ft x 12 ft
Carbon bed depth	13 ft
Carbon size	8 x 30 mesh
Flow per column	250 gpm
Surface loading rate	1.74 gpm/ft^2
Contact time	56 min
Carbon dosage	1 lb/1,000 gal
Weight of makeup carbon per bed	2,400 lb

Backwash

Supply	Treated effluent
Duration of backwash	10 min
Backwash rate	2,900 gpm
Bed expansion	40% max with surface washers

A downflow gravity carbon column arrangement was selected because of the suspended solids expected in the carbon column influent. Although the stormwater was to be stored in a large reservoir where solids would settle and floating oil would be skimmed, the impounded water would still contain sufficient amounts of suspended solids and oil to interfere with upflow carbon column operation. Backwashing capacity was provided to expand the carbon beds by 40 percent, and with a unique rotating surface washer; backwashing would breakup and remove filtered solids and accumulated oil.

A schematic flow diagram of the wastewater treatment facility is presented in Figure A-19. Water is pumped from the reservoir to the influent water

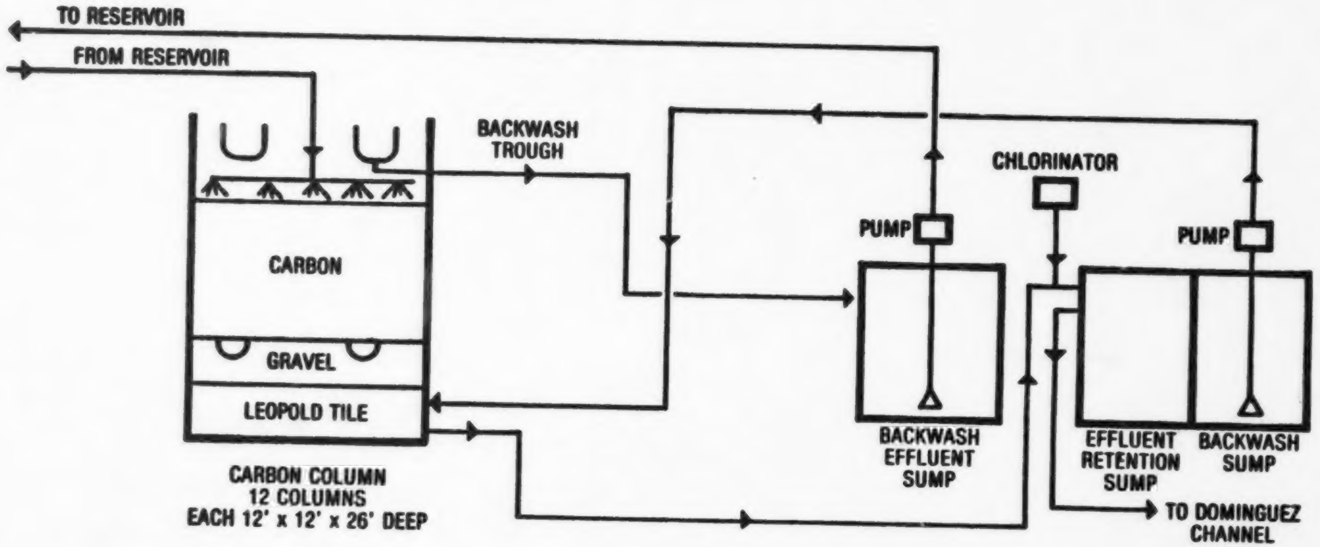
TO RESERVOIR
FROM RESERVOIR
BACKWASH TROUGH
CHLORINATOR
PUMP
PUMP
CARBON
GRAVEL
LEOPOLD TILE
CARBON COLUMN
12 COLUMNS
EACH 12' x 12' x 26' DEEP
BACKWASH EFFLUENT SUMP
EFFLUENT RETENTION SUMP
BACKWASH SUMP
TO DOMINGUEZ CHANNEL

Figure A-19. Granular activated carbon wastewater treatment system, ARCO Petroleum Products Co.

distributor at the treatment plant. The rate is controlled to each column by a flow control flume; it can, however, be varied to stagger the exhaustion of carbon as desired. The water passes down through the carbon and underdrain system and is conveyed to an effluent retention sump. Each bed of carbon is supported by a 1-ft thick layer of gravel, which is supported in turn, by a Leopold tile underdrain.

From the effluent sump, the treated wastewater flows to the Dominguez Channel. Chlorine can be added at the sump inlet if desired. This sump also serves as the reservoir for backwash water.

The carbon columns were designed for parallel operation in a downflow mode. Since the water is not filtered before being introduced into the carbon columns, the granular carbon acts as a filter for the remaining solid particles. The filtered solids gradually impede the water flow resulting in increased headloss. To prevent excessive headloss, the accumulated solids must be washed from the carbon beds. This is provided by a backwash pump located at the effluent sump. When the water level in a column rises to the bottom of the backwash trough, that column is shut down for backwashing. Treated water is pumped into the underdrain system of the column being washed at a design rate of 2,900 gpm (20 gpm/ft^2). The flow of water upward through the column causes it to expand and release the lighter solids; these light solids are carried into the backwash troughs and to a sump from which they are pumped with the water to the reservoir. The rotating surface wash at each column supplies additional agitation to increase solids removal from the expanded carbon bed.

Since the carbon treatment plant is used only when stormwater has accumulated in the large reservoir, it can be run at a very uniform rate independent of normal process wastewater flow variations. The concentration of organic materials in the influent water cannot, however, be controlled so that variation can occur.

Basis of Reactivation System

As the activated carbon becomes spent and no longer provides the desired removal of organic materials, it must be reactivated. A schematic diagram of the carbon reactivation system is shown in Figure A-20.

Carbon removal troughs are provided at the bottom of each column. The upper edges of the troughs are at the same level as the gravel that supports the carbon. To reactivate a carbon column, the spent carbon is moved by gravity along the troughs by high pressure water spray nozzles. The carbon slurry is transferred from the column via a larger concrete trough to a sump from which it is pumped to the spent carbon holding tank.

The holding tank is sized to contain all of the carbon from one column. The carbon is then transferred to a dewatering screw conveyor where the excess water is drained as the carbon moves up the inclined conveyor to the top of the reactivation furnace.

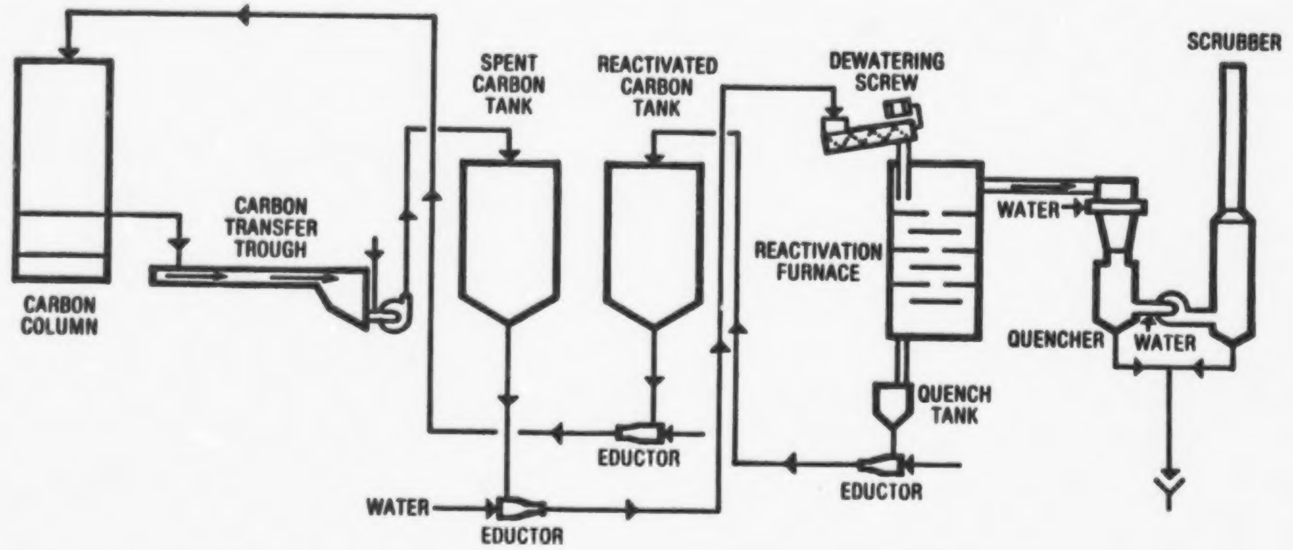
CARBON COLUMN
CARBON TRANSFER TROUGH
SPENT CARBON TANK
REACTIVATED CARBON TANK
DEWATERING SCREW
REACTIVATION FURNACE
WATER
SCRUBBER
QUENCHER
WATER
QUENCH TANK
EDUCTOR
EDUCTOR
WATER
EDUCTOR

Figure A-20. Granular activated carbon transfer and reactivation system, ARCO Products Co.

As the spent carbon enters the top of the furnace, it is deposited on the first hearth and is moved across each succeeding hearth by rotating rabble arms attached to a central shaft. Teeth mounted as plows on each rabble arm move the carbon inward or outward across the hearth. The temperature increases as the carbon moves through the furnace to provide the thermal reactivation. Automatically controlled burners are mounted at the lower hearths, and steam is added to aid in the reactivation process.

The reactivated carbon drops from the bottom hearth into a water quench tank where it is cooled before being transferred to the reactivated carbon holding tank. It is then transferred by gravity when needed to an empty adsorber cell.

Off-gases from the processing of the spent granular carbon require additional treatment before being discharged to the atmosphere. Air pollution codes in the Los Angeles basin are the strictest in the nation. To meet Air Pollution Control District requirements, an afterburner at the top of the reactivation furnace raises the off-gas temperature to about 1450°F and a quencher-scrubber system cools the gases and removes the final solid particles from the exiting gases.

Design Criteria - Carbon Reactivation Furnace

Furnace type	Multiple hearth
Furnace diameter	56-in. I.D.
Number of hearths	Six
Capacity	8,500 lb/day
Estimated carbon loss	5%
Fuel	Natural gas
Fuel requirements (including afterburner)	3,000 SCFH
Temperature, range	1,600°-1,750°F
Steam requirements	354 lb/hr
Afterburner type	Integral (zero hearth)
Apparent density - spent	0.54-0.56
- reactivated	0.48-0.50
Time to regenerate one bed	6 days

GAC SYSTEM PERFORMANCE

The full-scale carbon adsorption system was started up first on a trial basis in May, 1971, to get operating experience and permit correction of any operational deficiencies that might become evident. Process wastewater diluted with service water was used for the test since the rainy season would not begin until late in the year. The initial feed rate to the treatment plant was set at the design rate of 250 gpm carbon adsorber. The influent COD was 650 mg/L and the effluent COD ranged from 44 to 80 mg/L compared with the design effluent concentration of 37 mg/L COD. During the initial test run of 208 hr, the effluent became cloudly and a septic odor became evident. Washing the beds with a 2 percent caustic solution corrected the problem of cloudiness and septicity but did not improve the effluent COD.

In later stages of the testing period, the influent COD dropped to within the design concentration but the total COD in the effluent was nearly always greater than 37 mg/L. Other measures to improve COD removal such as more vigorous backwashing and more frequent backwashing were not successful.

It also became apparent that the carbon exhaustion rate was greater than had been expected from the pilot plant studies. When one carbon cell was run to complete exhaustion, the exhaustion rate was 7 lb/1,000 gal compared with the design exhaustion rate of 1 lb/1,000 gal at the design effluent concentration.

The first stormwater treatment period began in December, 1971, when sufficient rainfall accumulated for full operation of the treatment plant at the design rate of 3,000 gpm. Because of the intermittent occurrence of rains during that season, the treatment plant was operated six times during that season. The results of these runs are given in Table A-20.

TABLE A-20. TYPICAL PERFORMANCE DATA FIRST RAINY SEASON

Number	Length of run, hr	Feed Rate, gpm	Average COD Feed	Average COD Effluent
1	44	3000	326	43
2	48	3000-2000	360	48
3	38	2000	374	86
4	18	2000	310	67
5	95	1000	237	100
6	22	2000	147	93

Initially, the influent COD was higher than design so that feed rate was reduced in subsequent runs. The effluent COD, however, remained high, even after the influent COD concentration was lower in later runs because of more dilution. It was not determined whether the effluent COD consisted primarily of soluble organic materials that normally would be adsorbed. At one time during the first rainy season, the presence of algae in the influent to the carbon columns was responsible for high effluent COD. The algae was neither adsorbed nor removed by filtration so that it passed through the columns and was discharged. Although the algae contributed a nonsoluble COD, it constituted a portion of the total COD discharged. The COD loadings on the carbon in each column varied from 0.2 to 0.3 lb COD/lb carbon.

Suspended solids removal data are limited, but for one period during the first rainy season, the influent to the activated carbon columns averaged 106 mg/L and the effluent suspended solids averaged 22 mg/L.

Operational changes were made before the second rainfall season of 1972-1973 to try to improve the quality of the effluent and decrease the carbon dosage. Five of the carbon columns were placed in continuous service so that they would be reactivated and placed back in service during the season. The other seven columns were operated as before. In addition, treated water was recycled to the holding reservoir to reduce the concentration of the influent.

Figure A-21 shows the performance of one of the five continuously operated columns, which is typical of all five. Operation of the columns was discontinued and the carbon reactivated when the effluent COD concentration exceeded 50 mg/L. After reactivation and replacement, the column was operated until the effluent COD reached 100 mg/L.

Operating results for the remaining seven columns, which were operated in the design mode of once through flow and no regeneration, are given in Figure A-22. These columns were shut down for later regeneration when the effluent COD reached 50 mg/L.

Oil removal for the period shows that 57 percent of the influent oil concentration of 28 mg/L was removed; 12 mg mg/L remained in the carbon column effluent.

Average of data obtained in the 1972-1973 rainy period show that 102 mil gal of wastewater were treated; the influent and effluent COD concentrations of 233 mg/L and 48 mg/L, respectively, resulted in a carbon loading of 0.26 lb COD/lb carbon.

Reactivation System

The first adsorber was reactivated in November, 1971, and the second in February, 1972. Five other adsorbers followed in the April-July, 1972 period. The time required for reactivation of each varied from 4 to 14 days compared with the design regeneration rate of 5.7 days. Several factors contributed initially to the extended reactivation time including such problems as gravel plugging the feed eductor, eductor wear, poor temperature control, and high center shaft rates. After the original 1-in. eductor was replaced with a large 1-1/2-in. unit and the center shaft was slowed down, the reactivation time for, each column approached the design time and the apparent density of the reactivated carbon was within the design range. The following year no major problems were apparent in the carbon reactivation system, and the quality of the reactivated carbon was more nearly that of virgin carbon.

Actual carbon losses during reactivation were found to be about 5 percent which was attributed primarily to attrition during handling and reactivation. Any fines generated during the handling of carbon were backwashed out of the adsorbers before the adsorbers were placed in operation.

In April, 1973, the air pollution regulatory agency tested the reactivation furnace stack and determined that the limit for carbon monoxide (CO) was being exceeded. By increasing the afterburner temperature to about 1550°F and opening the combustion air damper, the plant was able to bring the CO level well below the limit.

Recent Discharge Modifications

In 1975, the Los Angeles County Sanitation District changed the sewer regulations affecting the ARCO Watson refinery. The new regulation permits stored untreated rainwater to be discharged to the sewer beginning 24 hr after

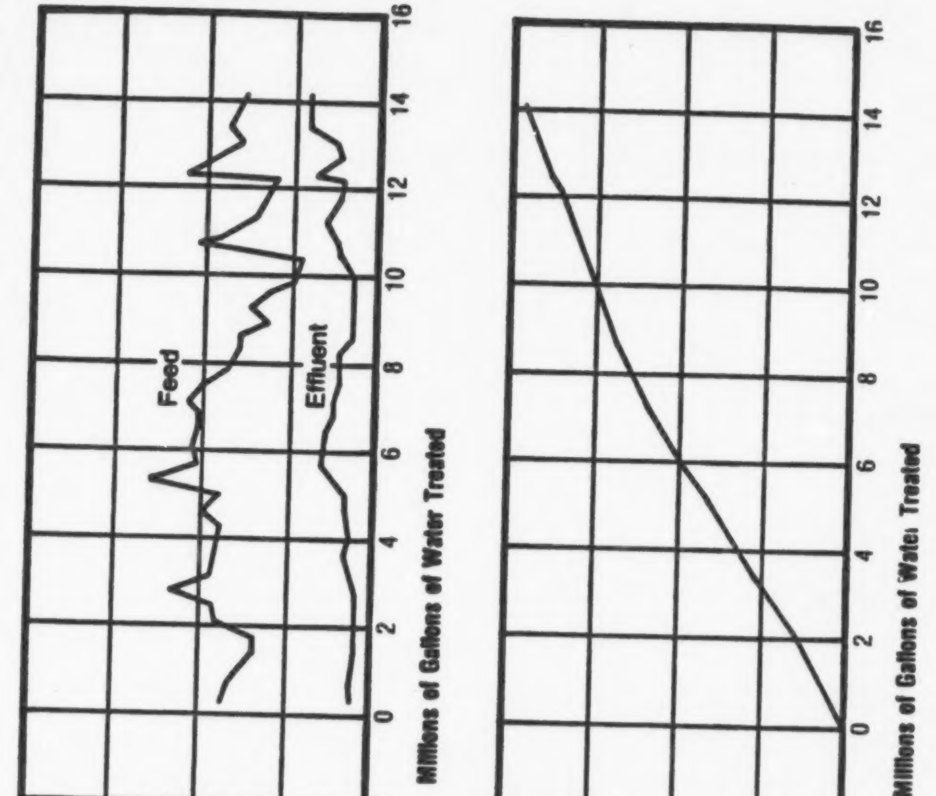

Figure A-21. COD removal and carbon loading of a continuously operated column.

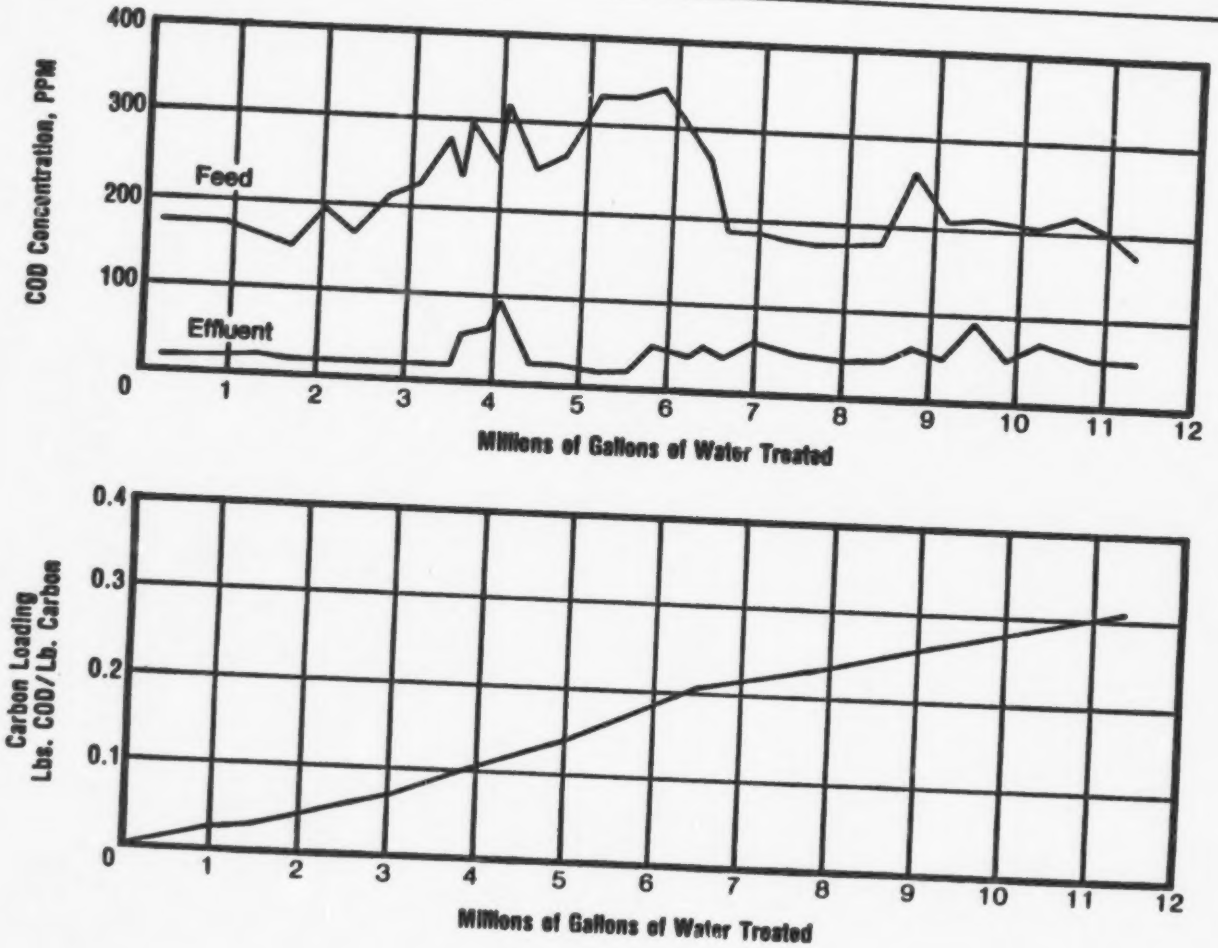

Figure A-22. COD removal and carbon loading - normal (design) operation.

the cessation of rainfall. Up to 10 mil gal can be discharged by the refinery during off-peak hours. In addition, the refinery can begin discharging normal process wastewater to the sewer beginning 4 hr after the rainfall ceases.

As a result of the newer regulation, the activated carbon treatment facility has seen very little operation in recent years. It was operated most recently during the 1977-78 rainy season. No operating or cost data are available for that period.

The refinery intends to keep the treatment system in operating condition so that in the future it can be placed in service if necessary. Very little corrosion has occurred because carbon steel parts of the system have been flushed well after each use period. Much of the system in which carbon is stored was constructed of concrete or stainless steel thereby eliminating excessive corrosion. To start up the adsorption and reactivation systems, only minor instrumentation repairs on the furnace would be required.

CAPITAL AND OPERATION AND MAINTENANCE

Capital Costs

The cost of the activated carbon plant including adsorbers, carbon transfer system, reactivation system, appurtenances, and initial fill of granular activated carbon, as installed, was approximately \$1.0 million (1971 dollars). This does not include the value of the plant site or other associated costs such as the holding reservoir or pretreatment facilities.

Operation and Maintenance Costs

The average cost to operate and maintain the activated carbon treatment plant over the first 2 years of operation (1971-1973) was \$0.49 per 1,000 gal of water treated based on actual figures supplied (not adjusted for later years).

A tabulation of operating and maintenance cost is presented in Table A-21.

TABLE A-21. OPERATING AND MAINTENANCE COSTS 1971-73

Item	$	¢ per 1,000 gal of water treated
Utilities	21,067	12
Maintenance labor	10,251	6
Operating labor	23,443	14
Carbon (makeup)	21,779	13
Miscellaneous (maintenance overhead and costs other than labor and transportation overhead)	7,249	4
Total	83,789	49

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CASE HISTORY NO. 10
RHONE-POULENC INC.
PORTLAND, OREGON
INDUSTRIAL WASTEWATER TREATMENT

HISTORY AND INTRODUCTION

Rhone-Poulenc Inc.'s manufacturing facility at Portland, Oregon, formerly known as Rhodia Inc., Chipman Division, manufactures herbicides such as 2, 4-D acid, MCPA acid, 2, 4-DB acid, and esters of these products. Wastewater from these processes originally discharged to an industrial lagoon located adjacent to the plant site. Regulation of Rhone-Poulenc's discharge began in 1966 when the Oregon State Sanitary Authority limited the discharge of phenols to a maximum of 25 mg/L and required that the discharged wastewater bypass the lagoon and be diverted directly to the river via a new pipeline. The plant installed a process for chlorinating the effluent followed by neutralization with lime and caustic soda to comply with the phenol limit. Within a year, the plant was notified that the City of Portland would build a system to collect and treat industrial wastes from the area industries and that the Rhone-Poulenc discharge could no longer be discharged to the river. Subsequently, it was determined that the effluent would be acceptable for discharge to the sewer except for phenol, which would be limited to a maximum of 1.0 mg/L. The characteristics of the untreated wastewater are given in Table A-22.

TABLE A-22. RAW WASTEWATER CHARACTERISTICS

Constituent	Concentration
Phenol and cresol	10 mg/L
Chlorophenols & chlorocresols	100 mg/L
2,4-D and MCPA	100 mg/L
Alcohols	1000 mg/L
Chlorides (as NaCL)	50000 mg/L
Sulfates (as Na_2SO_4)	8000 mg/L
BOD	2000 mg/L
COD	3600 mg/L
Total solids	62000 mg/L
Suspended solids	10 mg/L (varies with pH)
pH	0.5

To reduce the phenol concentration to below the stated maximum, the Rhone-Poulenc laboratory investigated various processes including conventional biological methods, treatment with chlorine and bromine, ozone, ion exchange, and activated carbon. Activated carbon treatment was the method selected because it was found to be the most effective based on phenol removal and cost.

Pilot plant tests were run at the plant to develop adsorption data, design parameters, and preliminary cost information. It was determined that not only were phenolics removed but 2, 4-D, acid, solvents, and alcohol were also removed. Adsorption was enhanced and suspended solids were minimized by maintaining a low pH through the adsorption process.

DESIGN OF GAC SYSTEM

From the pilot plant results and evaluation of the untreated plant discharge, the design parameters were established (Table A-23).

TABLE A-23. SYSTEM DESIGN CONDITIONS

Flow rate	150,000 gpd
Hydraulic surface loading rate	2.0 gpm/ft^2
Carbon reactivation frequency	One adsorber every 2 weeks
Effluent quality	1.0 mg/L phenol max
pH (for adsorption)	1.0 max
pH (range for discharge)	7.0 - 9.0

Operation of the adsorption system was to be continuous with the reactivation system being operated on an intermittent basis as required.

Basis of GAC Design and Operation

The purpose of the activated carbon adsorption process as used at Rhone-Poulenc was to remove phenolic compounds that would interfere with the biological treatment process used by the City to treat wastewaters. To meet the discharge criteria of 1 mg/L phenol maximum, the following design basis was established.

Activated Carbon Adsorption System

Number of carbon columns	Two
Type	Downflow, gravity*
Size of columns	8 ft ID x 35 ft ID x 35 ft high
Carbon bed depth	14 ft 6 in. each adsorber
Carbon size	12 x 40 mesh
Flow	104 gpm
Surface loading	2.0 gpm/ft^2
Contact time (empty vessel volume)	105 min
Carbon quantity	18,000 lb/adsorber

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*Later changed to upflow

A schematic diagram of the GAC wastewater treatment facility is shown in Figure A-23. Untreated wastewater is pumped to a 3,500 gal mixing tank from the manufacturing areas of the plant. After mixing, it is pumped at a constant rate

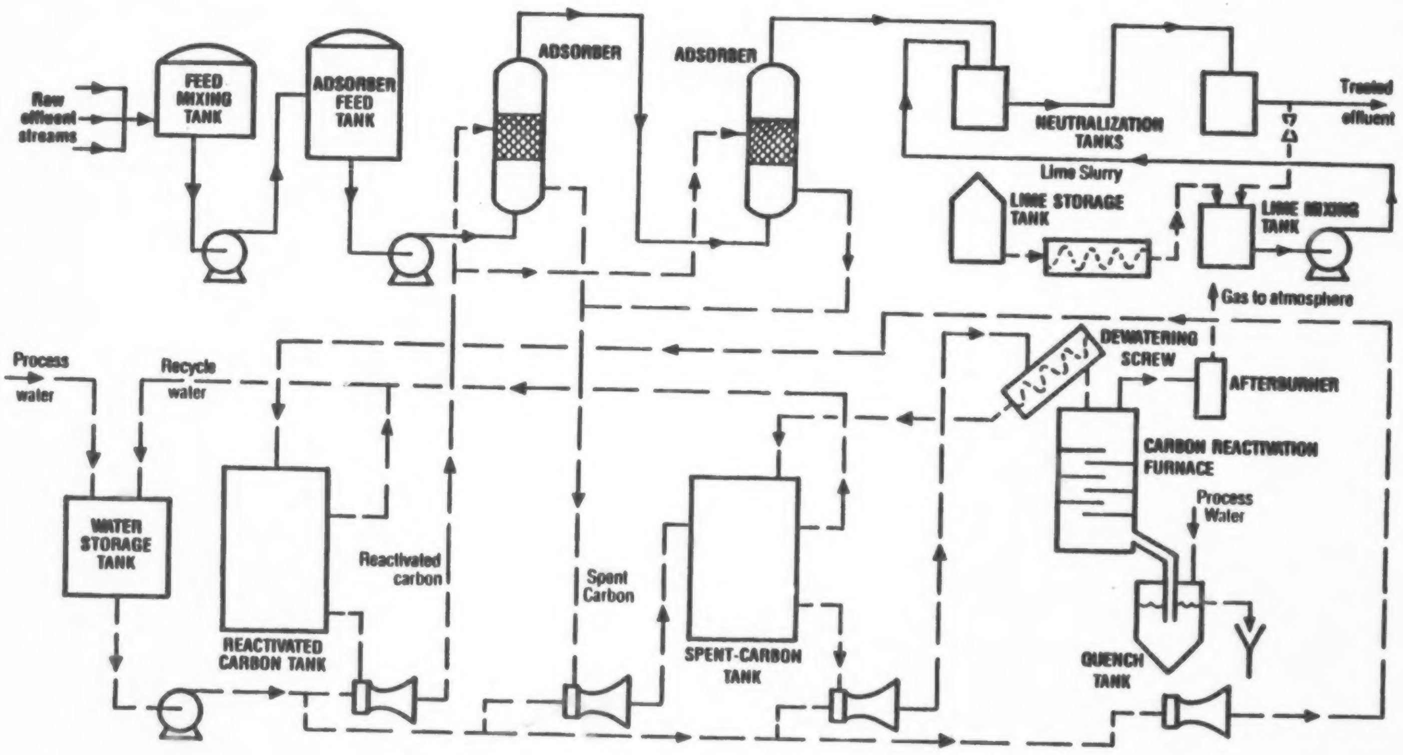
Raw effluent streams
FEED MIXING TANK
ADSORBER FEED TANK
ADSORBER
ADSORBER
NEUTRALIZATION TANKS
Treated effluent
Lime Slurry
LIME STORAGE TANK
LIME MIXING TANK
Gas to atmosphere
DEWATERING SCREW
AFTERBURNER
CARBON REACTIVATION FURNACE
Process Water
QUENCH TANK
Process water
Recycle water
WATER STORAGE TANK
REACTIVATED CARBON TANK
Reactivated carbon
Spent Carbon
SPENT-CARBON TANK

Figure A-23. Granular activated carbon wastewater treatment facility, Rhone-Poulenc, Inc.

to the adsorbers. The rate is set to provide a continuous and steady flow to the adsorbers regardless of the upstream fluctuations.

As shown in the schematic, the carbon columns were designed to operate in series although provision was made for parallel operation if desired. Wastewater enters the first column in the series from the bottom and flows upward through the carbon. From the top of the first column, it enters the bottom of the second and passes upward through the carbon in that column and exits just above the surface of the activated carbon bed. It then flows to a neutralization tank where lime is added to raise the pH to about 7.0 before being discharged to the sewer.

Although the columns are operated in an upflow mode, the original design and installation was for downflow operation. It was discovered that when spent carbon was removed from the column for reactivation, a "heel" of spent material remained in the column. Upon refilling with fresh carbon, adsorbed organics would leach from the heel and cause the effluent to contain phenol. Upflow operation prevents leaching of this material to the discharged effluent stream.

Since the wastewater contains no suspended solids at the low pH used in the adsorption process, no facilities were provided for backwashing the carbon columns.

All of the wastewater processing tanks including the adsorbers are made of wood (Douglas Fir) to withstand the corrosive acidic wastes being treated. The carbon bed is supported by a 1-ft layer of quartz gravel, which is supported on a perforated wooden distributor plate.

As the carbon in the first column of the series becomes spent (as evidenced by high phenol after the first adsorber, approaching the influent concentration, or by effluent phenol concentrations above 1.0 after the second adsorber), it must be reactivated. The first column is then taken out of service, and the second column continues to operate in a single-stage mode. Spent carbon is removed from the first adsorber to a spent carbon holding tank. Fresh carbon is then placed in the empty column, which is then operated as the second or polishing adsorber.

Spent carbon is removed from the bottom of an adsorber by opening a valve in the spent carbon line near the bottom of the adsorber just above the gravel layer. It is transferred in a water slurry via an eductor. To prevent leaving a large heel of spent carbon in the adsorber, a small quantity of water flows upward continuously through the distributor plate and gravel to slightly expand the carbon and cause it to flow toward the carbon drain so that only a small heel remains.

Basis of Carbon Reactivation Design

To reactivate the spent carbon, it is transferred from the spent carbon holding tank via an eductor to a dewatering screw conveyor. It is moved up an inclined trough by the screw conveyor, and the excess water is drained off back to the holding tank. Dewatered carbon containing about 50 percent moisture by weight drops from the end of the conveyor onto the top hearth of a multiple hearth furnace with the following design characteristics.

Carbon Reactivation Furnace

Furnace type	Multiple hearth
Number of hearths	Six
Furnace size	54 in.-I.D
Furnace capacity	8500 lb/day
Estimated carbon losses	5%
Afterburner type	External, horizontal
Fuel	Natural gas
Steam requirements	354 lb/hr
Regeneration time	2.1 days/bed

Rotating rabble arms attached to the central shaft move the carbon through the furnace by means of teeth attached to the rabble arms. The teeth act as plows to move the carbon inward or outward on succeeding hearths. Drop holes are located at the center of the furnace for inward moving hearths and at the outside for outward moving hearths; these holes permit the carbon to drop from hearth to hearth. In the upper hearths, the carbon is dried and some of the adsorbed organic materials are volatilized. Burners are located on Hearths No. 4 and 6 (Hearth No. 4 is at the top and Hearth No. 6 is at the bottom) so that the furnace is progressively hotter toward the bottom. Steam is added in the lower part of the furnace at a rate of 1 lb of carbon to aid in reactivation. The maximum temperature is in the range of 1600°-1800°F at the fired hearths. Off-gases from the reactivation pass upward through the furnace to an afterburner where they are burned at about 1800°F in the presence of excess oxygen to destroy any odor and burn the volatile gases that would otherwise be released to the atmosphere.

When reactivation of the carbon is complete, the carbon drops from the furnace into a water filled quench tank where it is cooled before handling and storage. From the quench tank it is transported in slurry form to a fresh carbon storage tank where it is stored until needed in one of the adsorber columns.

All carbon transfers are done in a slurry form by means of hydraulic eductors. Motive water used for transfer is recirculated to minimize the amount of water discharged to the sewer.

System Start-up and Operation

The GAC treatment facility at Rhone-Poulenc was first placed in service November 25, 1969. From the beginning it was able to produce an effluent meeting the established phenol limit of 1 mg/L. Originally it was planned to operate the plant at 150,000 gpd and to take the first adsorber off-stream for reactivation when it evidenced a phenol breakthrough, which was expected to result in an organic loading on the carbon of about 0.15 lb/lb carbon. At start-up, however, the flow rate was about half the design rate, and it was decided to operate the adsorption system until the phenol concentration of the first stage effluent approached that of the influent. This would provide for a much lower rate of exhaustion than originally planned. The resulting organic loading on the carbon--0.47 lb/lb carbon--made reactivation more difficult, and improved furnace operation; the adsorption system was returned to the designed operating procedure.

Because the carbon column discharge nozzel is located above the carbon bed, the depth of carbon in each column was reduced to 12 ft, instead of the original design depth of 14-ft 6-in., to prevent carbon losses by carryover. This results in a shorter empty vessel contact time of 87 min at the design flow rate compared with 105 min as designed.

During the first 4 months of operation, an average of 1.144 mil gal of wastewater was treated before reactivation of the first stage adsorber as compared with the design of 1.04 gal/adsorber.

In 1977, a new waste discharge permit issued by the City of Portland placed additional restrictions on Rhone-Poulenc for discharges to the sewer system. It limited the discharge of sulfates to a maximum of 500 mg/L and specified a minimum DO concentration of 1.0 mg/L. In addition, it required all wastewater to be held in one of three storage basins each of which holds the total process flow for an 8-hr period. No wastewater could be discharged until a completed analysis showed compliance with the regulations.

Also in 1977, the Oregon Department of Environmental Quality issued a permit for discharge of plant runoff and boiler and cooling tower blowdown to the Willamette River. Before that time, these discharges had not been restricted. The limits set fourth in the permit are shown in Table A-24.

TABLE A-24. DISCHARGE LIMITATIONS--PLANT RUNOFF AND COOLING TOWER BLOWDOWN

Constituent	Average concentration
Suspended solids	50 mg/L
Total phenolics	0.5 mg/L
Chlorinated hydrocarbons	1.35 mg/L
TOC	154 mg/L

Requirements were also set to require holding all of the nonprocess wastewater until analysis of the water could be completed. Wastes not in compliance must be returned to the plant for treatment.

To meet the terms of these permits, a new process wastewater treatment facility was installed that included new activated carbon columns and other treatment steps to ensure all other limits were met. The original carbon adsorption system was retained for treatment of contaminated stormwater and boiler and cooling tower blowdown on an intermittant basis as necessary. The new carbon treatment system was installed under a contract whereby the contractor would remove the spent carbon, reactivate it, and return fresh carbon to Rhone-Poulenc for both treatment systems.

Although the multiple hearth furnace used for reactivation of GAC started up in late 1969, and has operated intermittently as planned, it has been the primary area of major mechanical problems and maintenance expense. The plant shuts down 1 month each year for repair and maintenance. Originally, any repairs to the granular carbon adsorption and reactivation systems were to be done during the plant shutdown period. Major repairs to the furnace have been required, however, on a much more frequent basis.

Corrosion resistant materials were used throughout the furnace because of the corrosive conditions expected. Rabble teeth and arms on the upper two hearths were made of titanium, which lasted 8 to 9 months. The replacement teeth of ceramic-coated stainless steel were no improvement over titanium. Because of the cost of the coated teeth, the plant returned to using titanium teeth. On the other hearths, stainless steel teeth were replaced every 6 months.

The upper two hearths were replaced annually because of deterioration. After 2 years of operation, these upper hearths were coated with a moisture resistant, high temperature refractory that with minor operating changes, improved hearth life.

The original dewatering screw conveyor was made of Haveg because corrosive conditions were expected. The Haveg conveyor trough performed as expected, but the screw required replacement within 2 weeks because of excessive abrasion. Eventually, a 316 stainless steel screw conveyor was installed that lasted longer and cost less although it still was replaced at 3-month intervals because of corrosion.

SYSTEM PERFORMANCE

A summary of operating results of the reactivation system for 1971 and 1972 are given in Table A-25.

TABLE A-25. OPERATING RESULTS OF REACTIVATION SYSTEM

Constituent	1971	1972
Total wastewater treated, mil gal	25.08	31.08
Organics adsorbed, 1,000 lb	397.2	529.2
Carbon reactivated, 1,000 lb	1008	1344
Carbon exhaustion rate, lb carbon/ 1000 gal treated	40.19	46.49
Organic loading, lb organics adsorbed/lb carbon	0.39	0.37
Carbon losses, average percent	7.8	9.8

The organic loadings shown are higher than would be expected for a phenol removal system and reflect the adsorption of other organics. Carbon losses included some activated carbon lost from the columns into the effluent discharge line as well as reactivation losses. Actual losses ranged from 5 to 10 percent overall.

When initially started, low hearth temperatures prevented the spent granular carbon from being reactivated to virgin carbon quality. The original burners were replaced with larger burners to maintain an adequate temperature profile for reactivation. Typical fuel usage for reactivation was approximately 6500 Btu/lb spent carbon at a nominal reactivation rate of 300 lb/hr. That fuel use rate does not include fuel burned in the afterburner and is not correlated with furnace burner settings.

Since the contract adsorption and reactivation service was started in 1977, on-site reactivation by Rhone-Poulenc has been discontinued. The reactivation furnace has experienced severe corrosion of nearly all mechanical parts, exterior surface, instrumentation, and control panel. It would require complete rebuilding or replacement if on-site reactivation again became desirable.

CAPITAL AND OPERATION AND MAINTENANCE COSTS

Capital Costs

The total project cost including carbon columns, pumps, carbon handling system, reactivation system, appurtenances, and initial carbon fill was $300,000 (1969 dollars). Table A-26 shows the capital expenditure for the individual parts of the GAC treatment facility.

Operation and Maintenance Costs

Operating costs including maintenance for the year 1973 are shown in Table A-27 and are reported in 1973 dollars.

The operating costs shown are for the entire treatment facility and were not separated as to systems. Based on an actual wastewater flow of 70 gpm (100,800 gpd), the cost of treatment was $3.19/1,000 gal. Maintenance, the largest single item accounted for 36 percent of the total.

The costs for reactivating spent carbon for the year 1975 (1975 dollars) are shown in Table A-28.

Approximately 1,500,000 lb of spent carbon were reactivated in 1975 at an average cost of $0.125/lb. These figures do not include operating or maintenance of the adsorption system or other treatment units.

Costs presented here were developed by Rhone-Poulenc for comparison with the cost of a contract adsorption and reactivation service. Based only on these numbers, the contract service offered no cost savings. When the cost of lost production due to lack of reactivation system reliability was considered, however, the contract service was selected.

TABLE A-26. CAPITAL COSTS SUMMARY FOR RHONE-POULENC SYSTEM

Component	Cost, 1969 dollars
Carbon columns	13,300
Carbon storage vessels	10,400
Recycle water vessel	3,500
Quench tank	500
Pumps and eductors	5,900
Reactivation furnace (excluding installation)	35,400
Afterburner and stack	6,300
Off-gas scrubber system	10,000
Carbon dewatering screw	6,900
Piping and miscellaneous material	26,500
Electrical	11,000
Instruments	5,800
Structures and foundations	22,800
Carbon inventory	18,500
Construction labor	31,400
Engineering	21,800
Subtotal	230,000
Neutralization system	40,000
Water collection systems	30,000
Total	300,000

TABLE A-27. ANNUAL OPERATING COST SUMMARY FOR RHONE-POULENC SYSTEM

Component	Annual cost - 1973
Makeup carbon ($0.35/lb)	24,240
Fuel (natural gas)	7,680
Electricity	1,800
Steam	3,600
Operating labor	15,120
Maintenance	42,000
Depreciation (10%/year)	23,000
Total	117,440

TABLE A-28. COST OF CARBON REACTIVATION FOR RHONE-POULENC SYSTEM

Component	Cost, 1975 dollars
Makeup carbon ($0.54/lb)	40,500
Maintenance	87,200
Operating labor	15,000
Utilities - water	1,000
- electricity	2,500
- steam	16,300
- fuel (natural gas)	24,900
Total	187,400

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CASE HISTORY NO. 11
REICHHOLD CHEMICALS, INC.
TUSCALOOSA, ALABAMA
INDUSTRIAL WASTEWATER TREATMENT

HISTORY AND INTRODUCTION

Reichhold Chemical Inc.'s (RCI) manufacturing facility at Tuscaloosa, Alabama, is located adjacent to the Warrior Pool between the Oliver and Holt locks and dams on the Black Warrior River. This navigable stream is part of the Warrior-Tombigbee River system. The plant is relatively old; it began operations in the early 1940's with the manufacture of synthetic phenol. Through the years, its manufacture had expanded to include formaldehyde, orthophenylphenol, pentaerythritol, sulfuric acid, sulfate and sulfite salts of sodium, and various synthetic resins and plastics. Since the production units do not all operate continuously or simultaneously, the plant produces a complex wastewater stream of widely varying characteristics.

Until the mid 1960's, process wastewater mixed with large quantities of once-through cooling water and stormwater runoff was discharged to the Black Warrior River with little or no treatment and no discharge limits.

A combined study of RCI and the Alabama Water Improvement Commission in 1966 revealed the following approximate characteristics of the RCI discharge:

Flow (range)	10 to 15 mgd
Biochemical oxygen demand	16,444 lb/day
Chemical oxygen demand	26,718 lb/day
Phenolics	1,540 lb/day
pH (range)	5.4 to 12.3

Target reductions for waste discharges were established, and a requirement for a 5-day holding capacity (emergency storage) for all wastewater flows prompted RCI to begin searching for methods to reduce the total flow and to treat the process wastes. In-plant changes, which included process modifications and sewer segregation, ultimately reduced the discharge stream by 95 percent to about 500,000 gpd.

Discharge of the wastewater to a municipal sewer and treatment facility was not an available alternative since there was no secondary treatment plant in the area. The treatment and disposal methods RCI considered and evaluated as to their potential for meeting a desired discharge limit included deep well injection, evaporation/incineration, biological oxidation, and adsorption. A test well was drilled and tested, but was not considered a feasible method for disposing of the plant waste, although it remains a possible future discharge method for treated wastes. Because of several disadvantages including applicability limited to high strength wastes, evaporation/incineration was considered infeasible.

Based on the results of bench scale biological studies, an activated sludge pilot plant was installed and operated for several months to develop design criteria and establish a basis for estimating capital and operating costs. During the pilot plant operation, several waste streams were discovered which were not amenable to or interfered with biological treatment.

Adsorption methods using GAC were evaluated as a practical approach to treat the combined chemical wastes. The use of activated carbon provided the desired reduction of organics based on laboratory isotherm tests. A pilot plant using plexiglass columns was operated to establish design parameters, pretreatment requirements, expected effluent quality and cost estimates.

As a result of all the evaluations, RCI selected adsorption using GAC to remove soluble organics as the treatment method to be installed.

DESIGN OF GAC SYSTEM

As a result of the pilot plant operation and laboratory data, the unit operations selected for treating the wastewater included flow equalization, neutralization, clarification, and adsorption. A schematic flow diagram of this system is presented in Figure A-24. The combined process flow streams enter an equalization basin where the variability of concentration and flow are minimized. The wastewater is then pumped to a neutralization basin where acid is added to reduce the pH. Solids are removed by gravity settling in a clarifier, and the clarified wastewater is pumped to GAC columns. The treated wastewater then flows to a treated water tank and finally to the Black Warrior River. In an emergency or if the treated water is not of adequate quality for discharge to the river, it is diverted to a large holding basin.

Maximum permitted limits for discharge to the Black Warrior River are shown in Table A-29.

TABLE A-29. BLACK WARRIOR RIVER DISCHARGE LIMITS

Parameters	Limit
Biochemical oxygen demand	1644 lb/day
Chemical oxygen demand	2672 lb/day
Phenol	27 lb/day
Total suspended solids	200 lb/day
pH	6.0-9.0

Basics of GAC System Design and Operation

The purpose of GAC adsorption at RCI is to remove dissolved organics including phenol in the wastewater to meet discharge requirements.

An earthen equalization basin designed to hold approximately 3 day's flow was installed to level out flow and concentration variations. Untreated wastewater flows by gravity to the equalization basin, is pumped to an acid mixing

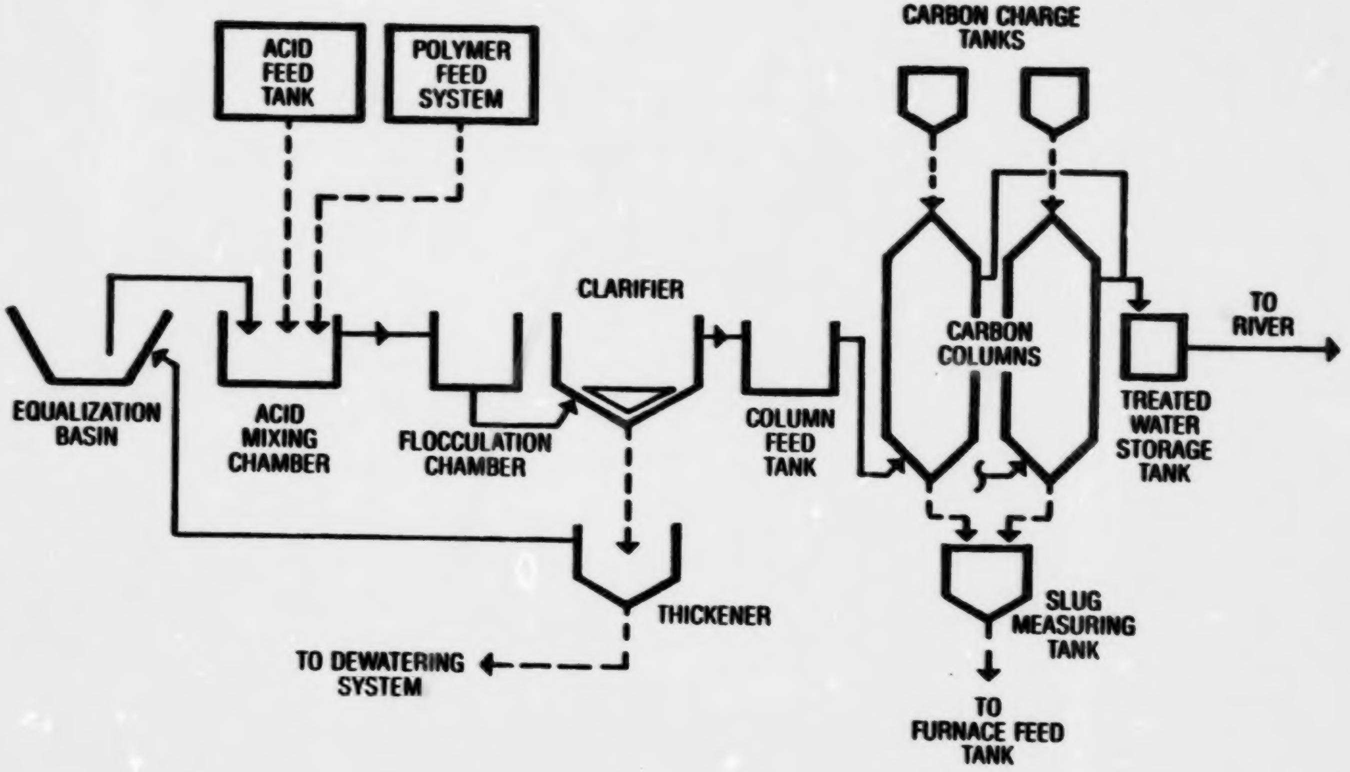
ACID FEED TANK
POLYMER FEED SYSTEM
CARBON CHARGE TANKS
CLARIFIER
CARBON COLUMNS
TO RIVER
EQUALIZATION BASIN
ACID MIXING CHAMBER
FLOCCULATION CHAMBER
COLUMN FEED TANK
TREATED WATER STORAGE TANK
THICKENER
SLUG MEASURING TANK
TO DEWATERING SYSTEM
TO FURNACE FEED TANK

Figure A-24. Flow diagram of wastewater treatment facility, Reinhold Chemical, Inc.

chamber where sulfuric acid is added to adjust pH to about 7.0; flows to a flocculation chamber where a polymer is added to improve solids flocculation; and enters a clarifier where the solids are settled and removed for disposal. The clarified water containing less than 42 lb/day of suspended solids (10 mg/L) is pumped to two GAC columns in parallel. The following was the design basis for the GAC treatment system.

Granular Activated Carbon Treatment System

Flow rate (average)	500,000 gpd
(maximum)	1,000,000 gpd
Number of carbon columns	Two in parallel
Type	Upflow, moving bed
Size of columns	12-ft diameter x 40-ft high
Carbon size	8 x 30 mesh
Carbon quantity (each column)	125,000 lbs
Column flow (each column)	175 gpm
Surface loading rate	1.55 gpm/ft^2
Contact time (empty bed)	100 min
Carbon exhaustion rate	65 lb/1000 gal (35,500 lb/day)

Each carbon column, made of carbon steel is lined with an epoxy material to prevent corrosion. The vessels are totally enclosed with conical sections at the top and bottom. Water enters each column via eight stainless steel conical screens connected to an external circular header. After passing upward through the column, treated water exits through an identical arrangement of screens and header system. Treated water then flows to a treated water holding tank from which it flows by gravity to the Black Warrior River. If it cannot be discharged, it flows to a treated water holding basin with a capacity for 5 days flow (2.5 mil gal).

As water passes up through the carbon column, the activated carbon in the lower portion of the column, which is in contact with the highest concentration of organics, loses its ability to adsorb additional organics (becomes spent). Periodically, a portion of the carbon is removed from the bottom and an equal amount of fresh carbon is admitted to the top of the column. In this way, the column is operated in a countercurrent mode and the freshest carbon is in contact with the highest quality water to achieve the maximum amount of organic removal.

Basis of Reactivated System Design and Operation

Figure A-25 presents a flow schematic of the carbon handling and reactivation system. The spent carbon slug, taken from the bottom of the column, flows to the slug measuring tank to ensure that the same amount of carbon is transferred each time. From the slug measuring tank, carbon flows by gravity to the furnace feed tank and is then hydraulically moved via an eductor to a dewatering screw conveyor located at the top of the multiple-hearth furnace. As the carbon slurry enters the dewatering screw conveyor, excess water drains off back to the furnace feed tank. The granular carbon is moved slowly up the

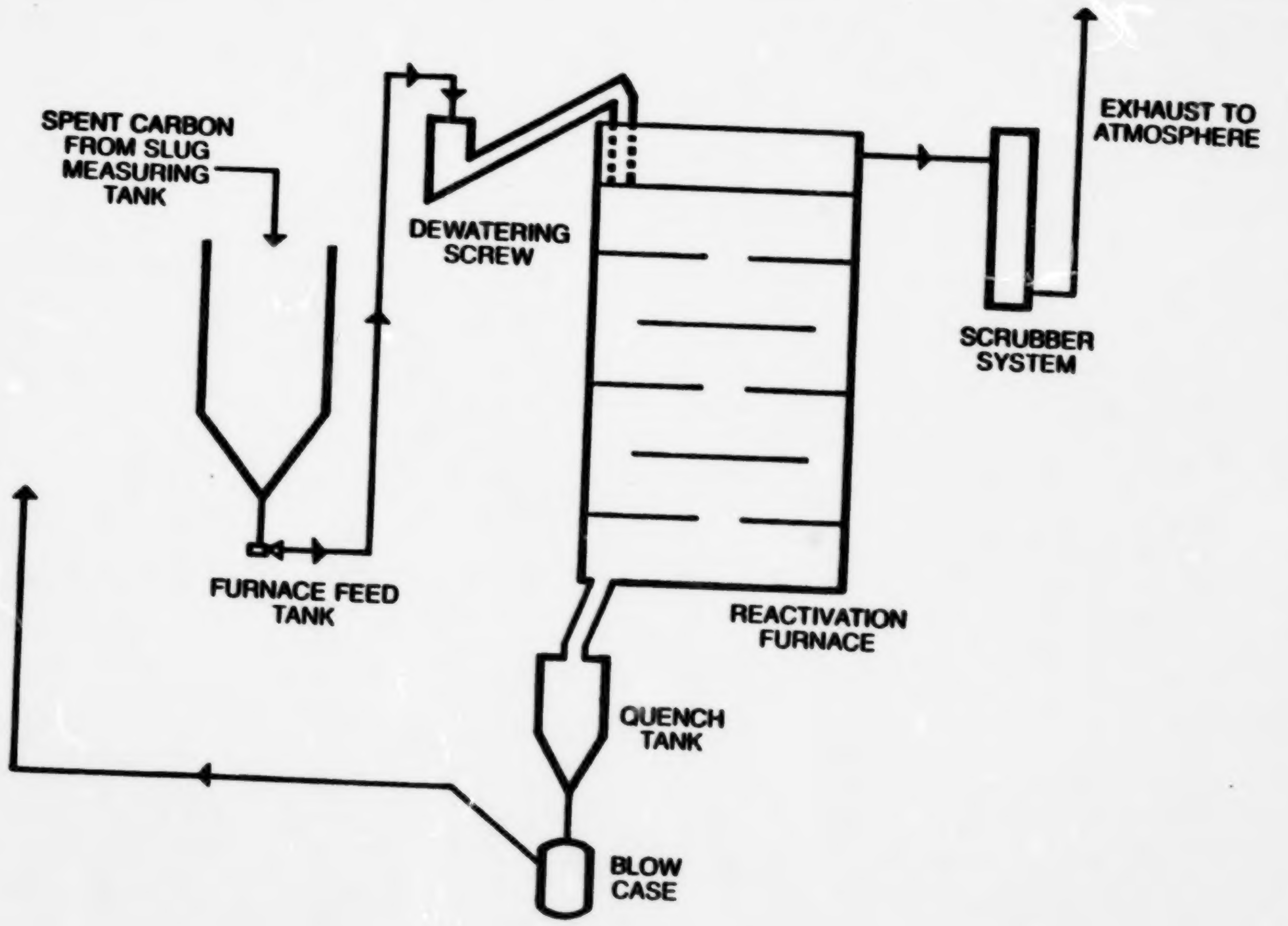
SPENT CARBON
FROM SLUG
MEASURING
TANK
DEWATERING
SCREW
EXHAUST TO
ATMOSPHERE
SCRUBBER
SYSTEM
FURNACE FEED
TANK
REACTIVATION
FURNACE
QUENCH
TANK
BLOW
CASE

Figure A-25. Carbon handling and reactivation system, Reinhold Chemicals, Inc.

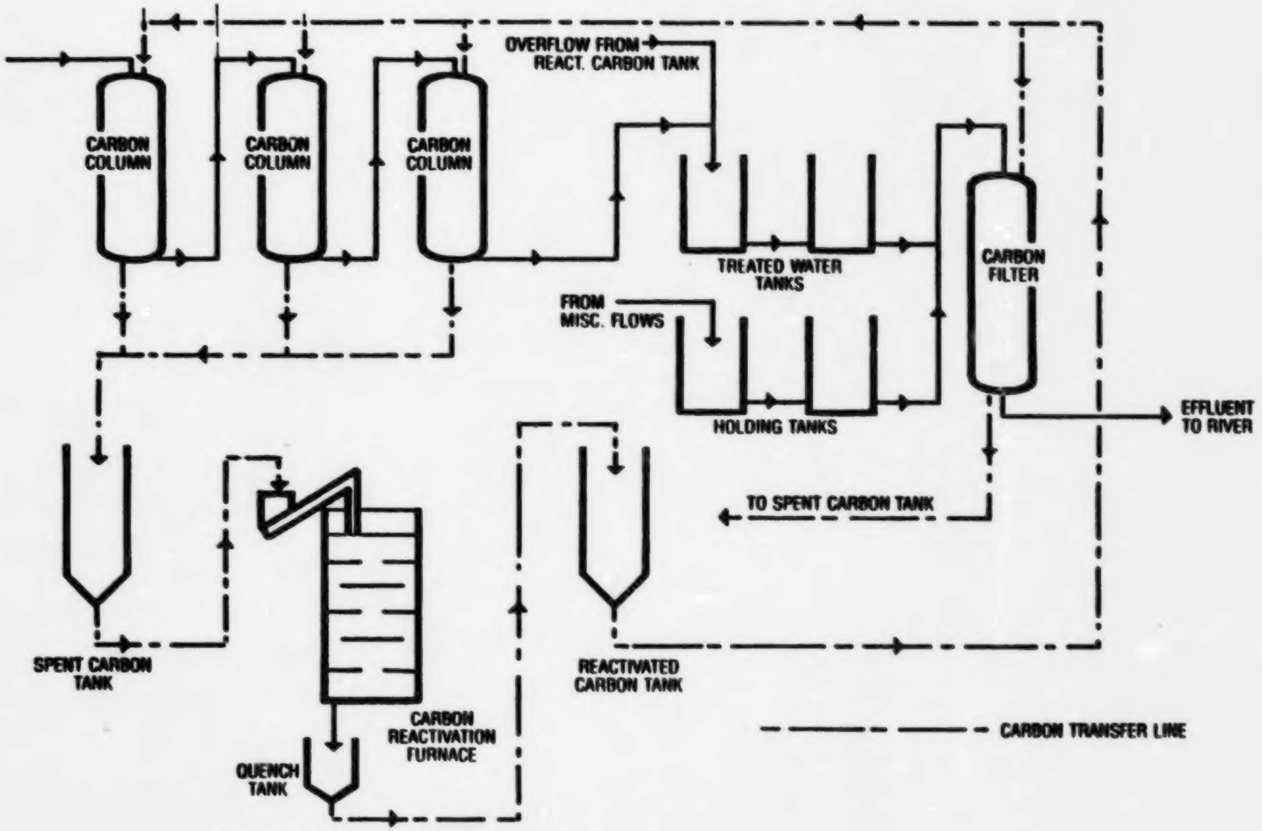
OVERFLOW FROM
REACT. CARBON TANK
CARBON COLUMN
CARBON COLUMN
CARBON COLUMN
TREATED WATER TANKS
FROM MISC. FLOWS
HOLDING TANKS
CARBON FILTER
EFFLUENT TO RIVER
TO SPENT CARBON TANK
SPENT CARBON TANK
CARBON REACTIVATION FURNACE
QUENCH TANK
REACTIVATED CARBON TANK
CARBON TRANSFER LINE

Figure A-26. Flow diagram of granular activated carbon treatment plant, Stephan Chemical Co.

inclined conveyor trough and is discharged onto the top hearth (Hearth No. 1) of the reactivation furnace. Spent carbon is moved across the hearth by angled teeth attached to rabble arms, which rotate by means of a central rotating shaft. After passing across the hearth, the carbon drops to the next lower hearth where the process is repeated, inward on one hearth and outward on the next, alternating each time.

On the upper hearths, moisture and some easily volatilized organics are driven off. Furnace temperatures increase from top to bottom; burners are located at Hearths 4 and 6 (Hearth 6 is the lowest hearth). Tempertures range from about 700°F at Hearth No. 1 to about 1700°F at Hearth No. 6. Steam is added on the fired hearths to improve reactivation.

As the hot reactivated carbon leaves the furnace, it drops into a water-filled quench tank where it is cooled and returned to a slurry form for transfer back to the top of the carbon column. A pneumatically operated blowcase transfers the reactivated carbon to the columns. Virgin makeup carbon is stored in a storage tank.

The following is the basis of design for the carbon reactivation system:

Granular Carbon Reactivation System

Furnace type	Multiple hearth
Furnace size	13-ft 6-in. O.D. x 6 hearth
Furnace capacity	32,500 lb/day
Fuel	Natural gas/L.P. gas
Afterburner, type	Internal (zero hearth)
Carbon loss per cycle	5 percent
Makeup carbon	1,625 lb/day

Furnace off-gases (combustion products, moisture, and volatilized organics) are heated in a gas-fired afterburner at the top of the reactivation furnace. Excess air is added to ensure combustion of volatile gases and odor. The gases then pass through a cooler and scrubber before being discharged to the atmosphere.

Operational Problems

Operating problems in the wastewater treatment system have included high turbidity in the final effluent and excessive pressure drop in the carbon columns. These problems were believed to have been caused by carryover of suspended solids from the clarifier and by biological activity in the columns.

From time-to-time, the polymer addition/flocculation processes are not effective in agglomerating the solids so they will settle readily in the clarifier. The result is a highly turbid feedwater to the carbon columns; this feedwater may be filtered by the carbon, causing high headloss and reduced flow, or the solids may pass through the columns causing effluent turbidity. Occasionally, changing the type of polymer will regain control of solids.

When biological activity increases in the columns, as sometimes occurs, the pressure increases and flow is reduced. This occurrence is reduced when adequate velocities are maintained in the columns.

Although the carbon columns were lined to prevent corrosion, leaks in the bottom cone required repair three to four times a year. In 1975, the bottom cones were replaced with 316 stainless steel cones. Rubber hose segments of carbon transfer lines, which required periodic replacement because of leaks due to abrasion, were replaced with pipe sections. Although leaks still occur, the repair frequency has been reduced.

The carbon transfer and reactivation system has performed basically as designed. Approximately 32,000 lb/day of spent carbon have been reactivated at about 5 percent loss.

Typical fuel usage is about 6,200 BTU/lb carbon reactivated, including fuel used in the afterburner.

Carbon slurry transfer lines and eductors tend to plug with debris or lumps of carbon. When this happens in the furnace feed line, no spent carbon reaches the furnace. When a stoppage is noticed and feed is restored, furnace control becomes difficult for a time and a poorly reactivated carbon may be produced.

Reactivated carbon quality as measured by iodine number has not approached that of virgin carbon because inoganics partially coat the reactivated carbon. Reactivated carbon iodine numbers are usually about 650 compared with 950 for virgin carbon. The furnace feed system was modified to use plant service water instead of treated effluent for transferring spent carbon to the dewatering screw. The intent was to remove some of the soluble inorganic salts from the carbon before reactivation to help restore the iodine number. This was only partially successful, and the iodine number remained low.

The reactivation furnace has always complied with established air pollution codes. No noticeable smoke or odor is discharged to the atmosphere although the maximum afterburner temperature is 1100°F compare with the 1400°F design temperature.

The most frequent and costly repairs have been to the multiple hearth reactivation furnace. Major repair-replacement items include rabble arms and teeth, hearths, and refractory. Shortly after startup, the material adsorbed on or remaining with the carbon in the furnace created an extremely corrosive condition causing the rabble teeth to wear down quickly. This condition still persists so that a large number of teeth must be replaced approximately every 4 months.

Major hearth repair or replacement of hearths has been required approximately every 2 years. Repair of other refractories, although less extensive than hearth repairs, are required when the furnace is shutdown for other maintenance.

The RCI wastewater treatment facility was started up in 1973. Quality of the treated water discharged to the Black Warrior River has always been within the established limits. Results of wastewater treatment by GAC for COD, BOD and phenol are shown in Table A-30 for the years 1973-1977. The original design conditions are shown for comparison.

TABLE A-30. ACTIVATED CARBON TREATMENT PERFORMANCE

	Constituent, lb/day						
	COD		BOD		Phenol		Flow,
Year	In	Out	In	Out	In	Out	mgd
1973 (April-Dec)	4668	2140	4687	1208	897	4.78	0.452
1974	9025	1504	3330	871	712	1.24	0.461
1975	9174	1830	3229	1008	761	0.95	0.354
1976	9700	1968	3971	1138	1022	2.05	0.359
1977 (Jan-July)	11099	2170	4031	1294	973	1.54	0.329
Design	28,000	2,672	16,000	1,644	2,700	27	0.50

Initially, some difficulty was experienced in maintaining the effluent COD within permitted limits. One stream containing organics not amenable to adsorption was the major cause of high effluent COD. When that stream was removed from the treatment system, COD was controlled within the limits. Control of COD and BOD can still be difficult at times when high concentrations of nonadsorbable organics or some types of inorganic materials are present.

Phenol removal has been much better than that required for discharge. Removal has consistently exceeded the design efficiency of 99.0 percent and typically exceeds 99.8 percent.

Although no data are shown for the period following July 1977, the quality of the discharge has not varied appreciably. The monthly average discharge quantities (in pounds per day) for July 1979 were 2,152 for COD, 1,364 for BOD, 0.14 for phenol. Flow for the same month averaged 277,000 gpd.

Ammonia nitrogen in the wastewater was not thought to be of concern, and no treatment was provided for ammonia removal. Ammonia quantities in the untreated wastewater are always less than any discharge limit. Ammonia concentration, however, increases through the carbon columns. In July 1979, ammonia averaged 107 lb/day at the carbon column inlet and 170 lb/day in the effluent; an increase of 58.9 percent. This increase may be because biological activity converts urea to ammonia within the carbon columns.

The carbon exhaustion rate has averaged about 79 lb/1000 gal wastewater treated compared with the design rate of 65 lb/1000 gal. Exhaustion of the carbon, which controls the column slugging frequency, is determined by COD measured at the outlet. Although routine tests also included phenol and BOD, COD (which is easily analyzed) breaks through more quickly. Carbon loadings have averaged 0.26 lb COD, 0.09 lb BOD, and 0.03 lb phenol/lb carbon. If carbon were regenerated on the basis of phenol breakthrough, the loadings would be much higher.

CAPITAL AND OPERATION AND MAINTENANCE COSTS

Capital Cost

Estimated capital cost for the complete wastewater treatment facility was $1.3 million. This estimate included the cost of engineering, equipment, and construction for the complete wastewater facility, i.e., earthen holding basins, pretreatment units, adsorption system, reactivation system, and initial charge of activated carbon. No breakdown of the capital cost for adsorption or reactivation systems is currently available.

Operation and Maintenance Cost

The annual cost of operating this wastewater treatment facility for the years 1973-1976 is presented in Table A-31.

TABLE A-31. ANNUAL OPERATING COST*

Item	1973	1974	1975	1976
Labor	88,080	82,607	95,539	102,845
Maintenance	57,324	111,034	172,828	161,871
Utilities	56,908	62,721	91,944	111,945
Carbon	182,892	258,119	348,462	320,671
Fixed expenses	109,234	122,967	129,602	144,373
Other	74,549	68,034	87,336	104,939
Total	$568,987	$705,482	$925,711	$946,644

*Actual dollars each year.

The cost figures are not separated as to treatment or process systems since the wastewater facility is operated and maintained as a unit. For this plant, the largest single expense item, about 35 percent of the total, is for makeup carbon. Furnace maintenance is reflected in the increase in maintenance cost from 1973 to 1976.

Although a breakdown of operating costs for later years is not available, the total cost of treatment plant operations for 1978 was $1,060,000.

Operating costs normalized to the actual quantity of wastewater treated each year are:

Year	$/1000 gal
1973	$3.79
1974	4.60
1975	7.87
1976	7.93

The 1979 monthly budget for wastewater treatment is approximately $90,000.

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CASE HISTORY NO. 12

STEPAN CHEMICAL COMPANY
BORDENTOWN, NEW JERSEY
INDUSTRIAL WASTEWATER TREATMENT

HISTORY AND INTRODUCTION

The Stepan Chemical Company's Fieldsboro plant at Bordentown, New Jersey, is located adjacent to the Delaware River south of Trenton, NJ. The plant is part of the surfactant division which makes surfactants for use in soaps and cleaners and for other uses. Sources of process wastewater include leakage from pumps and lines, tank washings, and minor spills. The present manufacturing facility has been in operation less than 15 years. About 10 years ago, the Delaware River Basin Commission placed discharge limits on the Stepan Chemical outfall that included a BOD_5 limit of 100 mg/L. To meet that limit, the company evaluated various treatment methods. A treatment method using GAC was found to provide the best results although it would not achieve the desired BOD_5 reduction. The State of New Jersey agreed with the company that a granular carbon treatment facility should be built and additional testing conducted in an attempt to meet the BOD_5 discharge limit.

Construction of the GAC wastewater treatment facility was completed for start-up in 1972. Since that time the plant has normally met the discharge requirements, including those established later by a NPDES permit, which are shown in Table A-32.

TABLE A-32. STEPAN CHEMICAL CO. - NPDES DISCHARGE REQUIREMENTS

Parameter	Limits, avg* (kg/day)
pH, range units	6-9
Suspended solids	0.6 kg/day
BOD_5	3.2 kg/day
COD	61 kg/day
TOC	12.3 kg/day
Oil and grease	0.55 kg/day
MBAS†	0.2 kg/day

*Maximum value for single sample is twice the average
†Methylene blue active substances

DESIGN DATA OF GRANULAR ACTIVATED CARBON COLUMNS AND REACTIVATION SYSTEM

The granular activated carbon treatment facility was designed to treat a waste having the following general characteristics: flow, 15,000 gpd; BOD, 2,000 mg/L; and COD, 9,000 mg/L.

Basis of GAC Design

The activated carbon adsorption system (Figure A-26) was designed according to the following conditions, which were established as the result of small column tests.

Carbon Adsorption System

Number of carbon columns	Three in series
Type of columns	Downflow, pressure
Column size	6 ft dia x 10 ft high
Bed depth	7.5 ft
Quantity of carbon	6,000 lb/column
Type of carbon	8 x 30 mesh
Required contact time	50 min
Carbon exhaustion time	430 lb/1000 gal

No preliminary treatment unit was included in the design so that untreated process wastes are pumped from a collection sump to the adsorption system. Wastewater enters the top of the first column, flows downward through the carbon bed, and passes out through the underdrain system. From there it flows to the top of the second column, through the second bed, and through the third column in the same manner. Each column in the series contains the same quantity of carbon and intermediate pumping is not necessary. After carbon treatment, the water is discharged to the Delaware River.

Whenever the carbon in the first column in the series cannot adsorb additional organic material (becomes spent), the column is taken off stream for reactivation of its carbon. This occurs about once each day. The column which was second in the series becomes the lead or first column, and column number three becomes number two. Spent carbon is removed from the column taken off-stream and transferred in a water slurry by hydraulic pressure to the spent carbon storage tank. This tank is sufficiently large to hold all of the spent carbon from one adsorber. Fresh carbon is then transferred to the empty carbon column, and it is placed in service as the new third column.

A small fourth carbon unit, not a part of the original design, was added to the treatment facility as a polishing filter for control of suspended solids. This filter, containing about one third of the standard column volume, is not considered one of the treatment columns and because of its low loading is reactivated approximately monthly.

Basis of Reactivation System Design

A reactivation furnace and carbon handling system is provided to reactivate the spent carbon to near its original characteristics. The following are the design criteria for this system.

Reactivation System Design Criteria

Furnace type	Multiple hearth
Number of hearths	Six
Furnace size	54 in. I.D.
Furnace capacity	6480 lb/day
Afterburner type	Internal, zero hearth
Fuel	L.P. gas

Spent granular activated carbon is transferred in a water slurry from the spent carbon tank via an eductor to a dewatering screw conveyor. In the dewatering screw conveyor, which is sloped upward, the spent granular carbon is gradually moved up the slope above the water level. Excess water is drained back to the spent carbon tank. Partially dried granular carbon containing approximately 40 to 50 percent moisture by weight falls from the end of the conveyor onto the top hearth (Hearth No. 1) of the reactivation furnace. It is moved across the hearth by teeth acting as plows, which are attached to rabble arms. The arms are fastened to a hollow central rotating shaft, and cooling air is circulated within the shaft and arms. As the carbon moves across the first hearth, it is dried and, upon reaching the center of the furnace, drops to the next lower hearth. The lateral movement of the carbon is repeated outward and continues in this fashion until it drops from the lowest furnace hearth (Hearth No. 6). As the carbon passes through the furnace, it becomes progressively hotter since burners are located near the bottom of the furnace (two burners each on Hearths Nos. 4 and 6). Maximum temperatures are normally in the range of 1600° to 1800°F.

Furnace off-gases including unburned volatile materials and combustion products, pass upward through the furnace to an afterburner. This unit is included as a special zero hearth at the top of the furnace where additional burners are mounted. Here the temperature is raised to the combustion point of the gases to burn the volatiles and odors that may exist. The furnace gases then are discharged to the atmosphere via the stack.

As the now-reactivated carbon exits the furnace, it drops into a water-filled quench tank where it is cooled. From there, it is transferred via an eductor to a reactivated carbon holding tank until it is needed in one of the carbon columns. At that time it is transferred in a water slurry via another eductor to the empty column.

Untreated river water is used to transfer carbon and to maintain minimum tank levels in the carbon handling system. This water becomes part of the plant discharge, accounting for approximately half of the outfall flow. It is not considered to need treatment as contaminated waste but must be filtered before discharge.

Recent changes in regulations regarding disposal of contaminated stormwater runoff have necessitated constructing a large 350,000 gal holding basin. This basin can be used to hold wastewater in the event of a treatment system breakdown as well as excess runoff. It is anticipated that a new treatment unit will be needed to treat this wastewater to augment the existing wastewater treatment facility.

SYSTEM PERFORMANCE

Although the adsorption system design was not considered capable of meeting the 100 mg/L BOD limit as originally required at Stepan Chemical, it has met or exceeded all requirements most of the time. This is because waste materials such as methanol, which are not amenable to adsorption on activated carbon, are removed from the adsorption system. These materials are held for disposal by incineration in a boiler. Reduced concentration of contaminants at the outfall is also partly due to dilution by the carbon transfer water.

The final carbon filter previously mentioned was installed to enable the discharge to comply with the outfall suspended solids limits. Carbon fines have continually plagued the wastewater treatment system by building up in the transfer and holding tanks and discharging to the river. The filter serves to prevent discharge of these fines and to control the discharge of suspended solids.

Table A-33 shows the average effluent quality at the outfall for 1977 and 1978.

TABLE A-33. TREATED EFFLUENT WATER QUALITY

Parameter	1977 avg	1978 avg
Suspended solids	24 mg/L	5 mg/L
BOD_5	26 mg/L	16 mg/L
COD	126 mg/L	117 mg/L
TOC	32 mg/L	19 mg/L
Oil and grease	1.0 mg/L	4 mg/L
Surfactants (MBAS)	0.26 mg/L	0.12 mg/L
Flow rate	28,800 gal/day	33,540 gal/day

One maintenance problem is erosion of elbows and piping in the carbon transfer system. In spite of the long radius elbows and flexible hoses currently used in the transport system, these items require replacement at regular intervals.

The carbon adsorption system was designed to treat 15,000 gpd of process wastewater. The actual amount treated averages about 11,000 to 12,000 gpd. The carbon exhaustion rate has averaged about 500 lb/1,000 gal compared with the design rate of 430 lb/1,000 gal.

The reactivation furnace has been operated at a nominal rate of 6,000 lb/day. This rate is determined by the amount of carbon in one vessel as one carbon column is reactivated each day. Early in the operation of the treatment facility, the effluent from each column was analyzed for COD on a frequent basis. It was soon discovered that one column should be reactivated each day to maintain the optimum maximum organic removal consistent with good furnace operation. Consequently, the routine daily reactivation of the lead column was established, and frequent analysis of the waste stream was discontinued.

No routine evaluation of reactivation process parameters such as the apparent density test is currently practiced. Instead, the furnace is operated on the basis of furnace draft and hearth temperatures, which are closely monitored. Current losses average about 6 percent, based on a reactivation rate of 6,000 lb/day and annual carbon purchases of 130,000 lb (350 lb/day).

Shortly after start-up, the furnace experienced a high rate of corrosion of the rabble teeth and rabble arms. Replacing the original teeth with teeth of different materials was done with no positive results. Some of the teeth required replacement as often as monthly regardless of materials used. The problem was eventually solved when the steam lines became plugged. Without steam, corrosion of the teeth was much less severe so that replacement is now required about every 6 months.

Operation of the afterburner has been discontinued with no noticeable effect on stack emissions. No odor is noticeable, and air quality limits have not been exceeded according to tests. The decision to discontinue its operation was based on fuel costs (L.P. gas) when it was found that afterburner fuel demand equaled the reactivation fuel demand.

CAPITAL AND OPERATION AND MAINTENANCE COSTS

Capital Cost

The initial capital cost of the GAC wastewater treatment and reactivation facility, including the initial charge of activated carbon, was about $225,000 in 1973 dollars.

Operation and Maintenance

Recent cost calculations show that the treated water costs are $0.025/gal ($25/1,000 gal). This is the total cost including makeup carbon, fuel, electricity, labor (both operating and maintenance), maintenance materials and depreciation. Fuel (L.P. gas) use for reactivation is 110,000 gal/yr, which results in a heat demand of 6,000 Btu/lb carbon reactivated. Fuel cost for reactivation is $0.02/lb carbon.

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CASE HISTORY NO. 13

REPUBLIC STEEL CORPORATION
CLEVELAND, OHIO
INDUSTRIAL WASTEWATER TREATMENT

INTRODUCTION AND HISTORY

The Cleveland district steel mill of Republic Steel Corporation at Cleveland, Ohio, is a completely integrated mill producing a variety of finished and semi-finished steel products. At the beginning of the process, coke for use in blast furnaces is produced from coal in the coke plant. In the process of coke production, wastewaters containing organic and inorganic materials are generated or released and, because of their nature, cannot be discharged without treatment. Among these materials are oils, ammonia, phenols, cyanides, and suspended solids. They are most commonly contained in three major process streams: crude ammonia liquor, barometric condenser water, and intercepting sump water. Typical concentrations of contaminants in the coking waste for a 6,000-tpd coke plant are shown in Table A-34.

TABLE A-34. CONTAMINANTS IN COKE PLANT* WASTE STREAMS

Stream	Flow (gpm)	Concentration, mg/L CTR			
		Ammonia	Phenol	Oils	Cyanide
Crude ammonia liquor	150	5,000	2,000	1,000	20
Barometric condenser water	1,000	20	40	20	40
Intercepting sump water	300	150	300	10,000	100

*6,000 tpd code production

In the early 1970's, Republic Steel Corporation began to look for an economically feasible treatment process for coke wastewater.

Some of the conventional processes considered by Republic Steel for treatment of the coke waste streams included phenol removal by solvent extraction, ammonia removal by limed ammonia still, and biological treatment of the combined wastes. Based upon a review of available treatment technologies, adsorption using GAC for phenol and organic removal was chosen for testing and development. Among the reasons for its selection was its ability to perform regardless of normal fluctuations of pH, temperature, flow, and organic concentrations. Since GAC can also be reactivated and reused, the process was considered to be potentially economically feasible.

GAC Testing

Laboratory testing was conducted by treating samples of the wastewater streams with activated carbon to develop preliminary adsorption isotherm data. Based on favorable results of the laboratory tests, pilot scale carbon columns were operated on the barometric condenser water stream. Pilot plant data verified the laboratory data and yielded a carbon exhaustion rate of 5.3 lb/1,000 gal of barometric condenser water.

All three streams were then blended according to their respective flow rates for testing in the pilot plant. These streams were found to be incompatible for combined testing; because the crude ammonia liquor contained 30 to 50 times more phenol than the other streams, extremely high carbon exhaustion rates resulted. A separate carbon adsorption system would be required for the crude ammonia liquor in a full-scale treatment plant.

Pilot plant results also showed that the intercepting sump water from the light oil refining plant contained large amounts of free and emulsified oils that were not suitable for adsorption. The emulsified oils passed through the column without being adsorbed, and the free oil coated the carbon particles thereby reducing their ability to adsorb phenol. Pretreatment of that stream to remove oils would be required before combining it with the barometric condenser water for phenol removal in the activated carbon adsorption process.

An oil removal method was developed during the pilot plant studies that included chemical treatment with spent pickle liquor and caustic soda to form an insoluble iron precipitate to which oil would adhere. The chemically treated water was then clarified in a dissolved gas flotation unit. Some of the cyanide was also removed by precipitation in this clarification process. The clarified liquid waste stream was then suitable for adsorption on activated carbon.

During the pilot plant studies, the barometric condenser was replaced with a surface condenser, significantly reducing the amount of water to be treated. Also light oil refining was discontinued before completing the activated carbon system design; this resulted in a significant reduction of emulsified oil.

DESIGN AND OPERATION

On the basis of laboratory and pilot plant test results and of the need to limit discharges from the Cleveland district coke plant outfall, a treatment system was designed to treat crude ammonia liquor to meet the following limits:

Ammonia	250 lb/day*
Phenol	2.5 lb/day
Cyanide	40 lb/day
SS	100 lb/day
Oil and grease	25 lb/day
pH	6-11

The system as designed provides for separate treatment of crude ammonia liquor and ammonium sulfate surface condenser condensate (Stream A) and of intercepting sump water, surface condenser ejector, and secondary condenser waters (Stream B). Stream B is used for quenching coke after treatment.

Basis of GAC System Design and Operation

The GAC adsorption systems were designed to reduce the phenol concentration in Stream A from 4,216 lb/day to 2.5 lb/day and in Stream B from 1,363 lb/day to 2.5 lb/day. Since Stream B is not discharged, the effluent phenol in that stream is not included in the outfall loading. Figure A-27 shows the flow diagrams for both activated carbon treatment systems.

Before entering the treatment system, Stream A first passes through a dephenolizer where the phenol concentration is reduced from 1,600 mg/L to about 30 mg/L. If the dephenolizer is not in operation, the wastewater can be treated with spent pickle liquor and caustic soda and sent to a dissolved gas flotation system. The stream is then passed through a multi-media filter where the suspended solids are reduced to about 15 mg/L.

After filtration, the wastewater enters the top of the first carbon column, flows downward through the carbon, and exits from the bottom. It then enters the top of the second column, flows downward through the carbon bed and out to the ammonia still from which it is discharged to the receiving stream. Since the carbon columns are pressurized steel vessels, no intermediate pumping is required.

Periodically one column is taken off stream for reactivation. This occurs whenever the first column effluent contains phenol greater than 5 mg/L. After the spent carbon is removed, reactivated carbon is placed in the column and the column is returned to service as the second or polishing column.

In a similar fashion, Stream B is treated with waste pickle liquor and caustic soda, passed through a dissolved gas flotation unit and mixed media filter, and it then flows through two series-connected downflow activated carbon columns as previously discussed. Effluent from this treatment system receives no further treatment since it is suitable for coke quenching.

Because of the low solids concentration in the filter effluent and the rate of carbon exhaustion, no provision was made for backwashing of the GAC columns.

When the carbon in one column in either system loses its ability to adsorb additional phenol (becomes spent), as determined by effluent phenol concentration, it is transferred in a water slurry from the column to the spent carbon storage tank near the reactivation furnace. It then flows in a slurry by gravity into a dewatering screw conveyor that moves the carbon slowly up an inclined trough and allows excess water to drain from the carbon. The drained carbon is then discharged into the reactivation furnace.

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*Ammonia limit was later changed to 500 lb/day

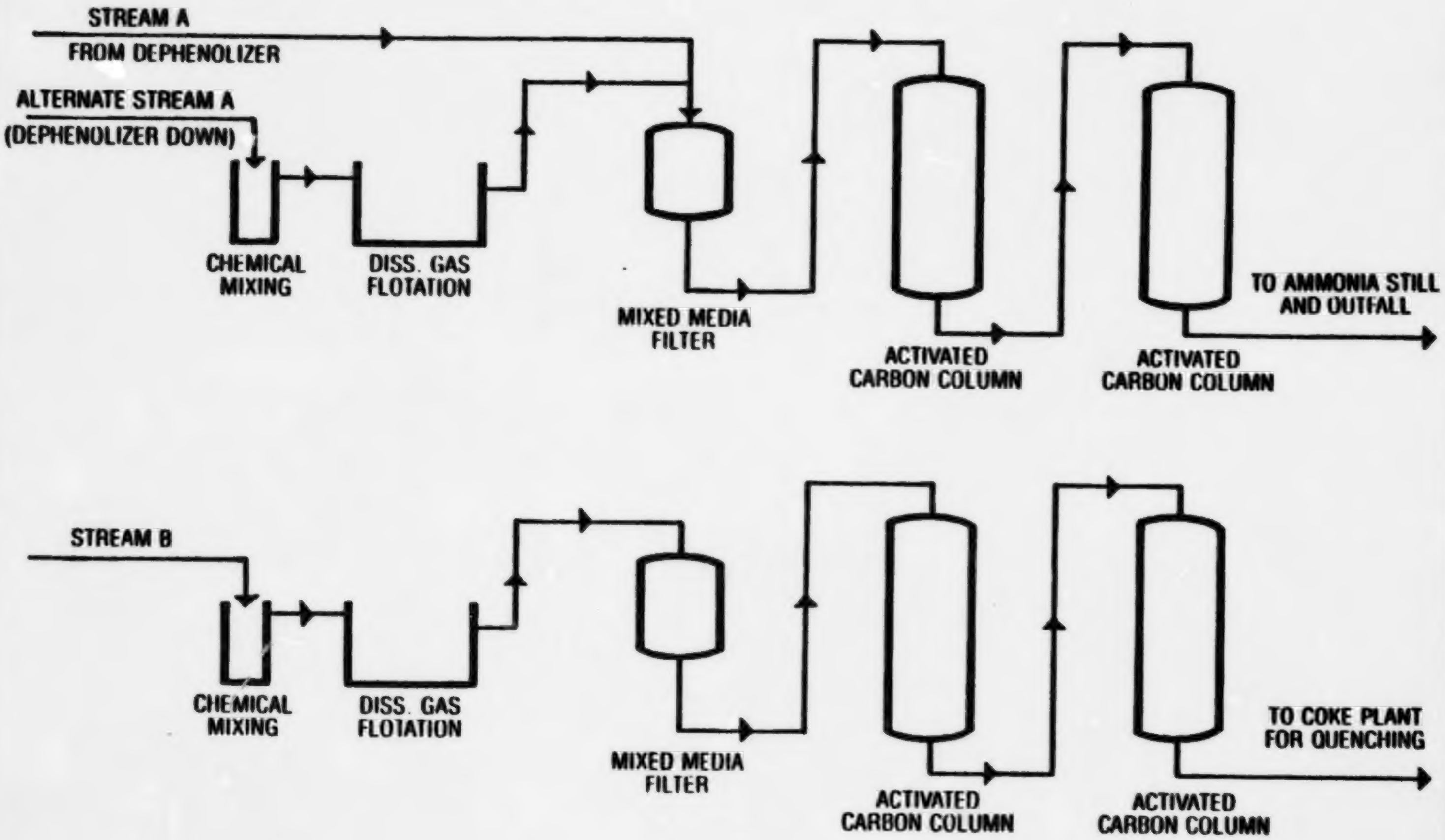
STREAM A
FROM DEPHENOLIZER
ALTERNATE STREAM A
(DEPHENOLIZER DOWN)
CHEMICAL MIXING
DISS. GAS FLOTATION
MIXED MEDIA FILTER
ACTIVATED CARBON COLUMN
ACTIVATED CARBON COLUMN
TO AMMONIA STILL AND OUTFALL
STREAM B
CHEMICAL MIXING
DISS. GAS FLOTATION
MIXED MEDIA FILTER
ACTIVATED CARBON COLUMN
ACTIVATED CARBON COLUMN
TO COKE PLANT FOR QUENCHING

Figure A-27. Flow diagram of granular activated carbon wastewater treatment system, Republic Steel Corporation.

The empty carbon column is refilled with reactivated carbon from the reactivated carbon storage tank. A small quantity of virgin carbon is added to the column to makeup for that lost (usually about 5 to 8 percent) during transfer and reactivation.

The adsorption system design criteria is as follows:

Granular Carbon Adsorption System

Stream A	Flow	220 gpm
	Number of carbon columns	Two
	Type	Downflow, series
	Column size	11.0 ft diameter x 24.5 ft high
	Carbon bed depth	18 ft
	Surface loading rate	2.3 gpm/ft^2
	Contact time (empty bed)	116 min total
	Carbon quantity	48,000 lb each
Stream B	Flow	440 gpm
	Number of carbon columns	Two
	Type	Downflow, series
	Column size	11.0 ft diameter x 24.5 ft high
	Carbon bed depth	18 ft
	Surface loading rate	4.6 gpm/ft^2
	Contact time (empty bed)	58 min total
	Carbon quantity	48,000 lb each

Basis of Reactivation System Design and Operation

The purpose of the carbon reactivation system is to restore the activity of the spent or used carbon to near its original characteristics for reuse at a more economical cost than if virgin carbon were used. This reactivation takes place in a furnace at maximum temperatures of 1,600° to 1800°F in the absence of excess oxygen. Steam is used to improve the quality of the reactivated granular carbon. The following is the design criteria for the reactivation furnace:

Carbon Reactivation Furnace

Furnace type	Multiple hearth
No. of hearths	Eight
Furnace size	16-ft O.D.
Furnace capacity	68,000 lb/day carbon, dry basis
Afterburner type	Internal (zero hearth)
Fuel, primary	Natural gas
alternate	Coke oven gas

Dewatered spent carbon containing 45 to 50 percent moisture by weight enters the furnace as it falls from the dewatering screw onto the top hearth (Hearth No. 1). It is moved across the hearth by means of rotating rabble arms attached to a central shaft. Stainless steel teeth mounted on the rabble arms act as plows to move the carbon and expose it to the hot furnace gases. As the carbon moves across the hearth, it drops through a hole to the next lower hearth where the rabbling process is repeated; the carbon is moved inward and outward on succeeding hearths. As the carbon moves downward through the furnace it becomes hotter. Drying of the carbon and volatizing of the organics takes place in the upper hearths, and reactivation is accomplished on the lower hearths. Burners are located at Hearths No. 4, 6, 7, and 8 (the bottom hearth), and steam is added at a rate of 1 lb steam/lb carbon. Maximum furnace temperatures occur at Hearth No. 8.

Off-gases from reactivation are drawn upward through the furnace and afterburner where they are incinerated at 1600°F to prevent the discharge of objectionable odors to the atmosphere. The heated gases then pass through a quencher and scrubber that cools the gas and removes much of the fine particulate material including carbon fines and ash.

After reactivation, the carbon falls into a quench tank at the furnace outlet. Water is maintained in the tank to cool the hot incandescent carbon and to maintain an air-tight seal on the furnace outlet. From the quench tank, the reactivated carbon drops into a blow-case that is pressurized with air to move the carbon to the reactivated carbon storage tank. The carbon handling system and reactivation flow diagram are shown on Figure A-28.

Operational Problems

The carbon columns are made of carbon steel with a vinylester lining to prevent corrosion. These linings have failed on occasion and have been repaired using the same lining material. A more suitable lining material is currently being sought.

Operating problems with the multiple hearth reactivation furnace have included insufficient temperatures in the afterburner and instances of corrosion. The afterburner was designed to operate at about 1600°F. During actual operation under steady-state conditions, the maximum afterburner temperature is typically 1,350°F. No serious odor problems have been detected as a result of the lower temperatures nor is there any record of violation of air quality limits.

The water recirculation line to the off-gas precooler and scrubber, originally of carbon steel, was replaced with stainless steel because of corrosion caused by sulfur dioxide (SO_2) in the gas. Portions of the stack also corroded because of the SO_2. In some areas of the stack 304 SS has been used in place of 316 SS. When these were replaced by the proper material, corrosion was no longer a problem.

SYSTEM PERFORMANCE

The GAC treatment system began continuous operation in July, 1977. From the beginning, the treated effluent quality has met or exceeded the design phenol performance. The discharged effluent from treatment Stream A typically contains 0.025 mg/L phenol.

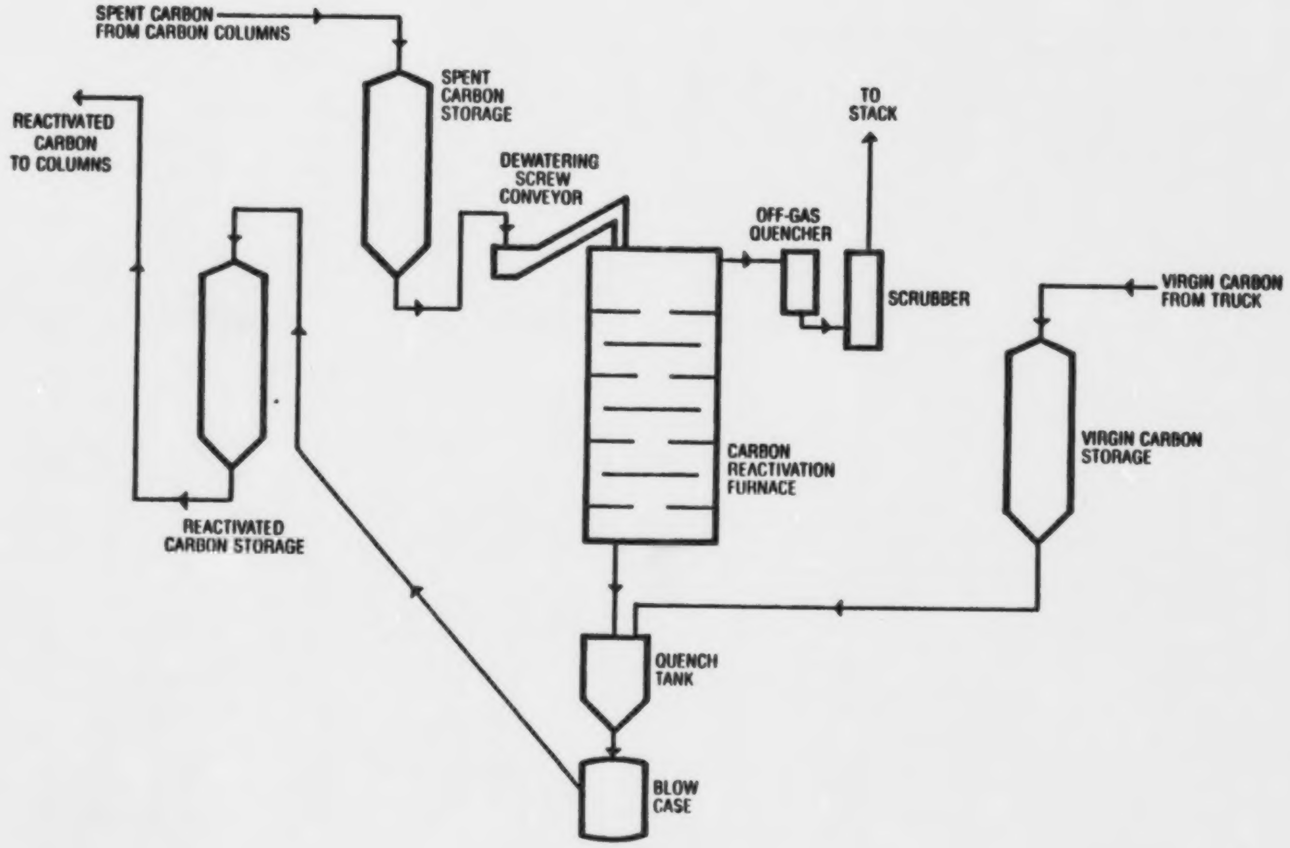
SPENT CARBON FROM CARBON COLUMNS
SPENT CARBON STORAGE
REACTIVATED CARBON TO COLUMNS
DEWATERING SCREW CONVEYOR
TO STACK
OFF-GAS QUENCHER
SCRUBBER
VIRGIN CARBON FROM TRUCK
VIRGIN CARBON STORAGE
CARBON REACTIVATION FURNACE
REACTIVATED CARBON STORAGE
QUENCH TANK
BLOW CASE

Figure A-28. Flow diagram of granular activated carbon handling and reactivation system, Republic Steel Corporation.

Carbon exhaustion rates have averaged about 35 lb/1,000 gal and 25 lb/1,000 gal for Streams A and B, respectively. The reactivation furnace, designed to reactivate 68,000 lb/day of spent granular carbon, has been operated at an actual rate of 20,000 lb/day. Quality of the reactivated carbon as measured by iodine number is in the range of 860 to 870 compared with 900 minimum for virgin carbon.

Initial carbon losses were high with some reactivation cycles showing 20 percent loss. More recently they have been averaging about 8 percent.

During the initial start-up period in late 1976 and early 1977, effluent phenol would occasionally exceed the discharge limits even though the carbon columns were fresh. This difficulty was traced to a defective valve that allowed untreated wastewater to bypass the columns. The valve was repaired and the problem was alleviated.

Phenol would leach from a heel of spent carbon that remained in the columns after spent carbon was removed. Even though reactivated carbon was placed in the column, the small amount of spent carbon would cause the effluent phenol concentration to exceed discharge specifications. A method was found whereby all of the spent carbon could be removed from the column during transfer.

CAPITAL AND OPERATION AND MAINTENANCE COSTS

Capital Costs

The original capital cost for the treatment facility which included chemical treatment, dissolved gas flotation, mixed-media filtration, solids dewatering and disposal, GAC adsorption and reactivation, was about $10 million. An exact figure is not available since Republic Steel did the construction. The cost for the adsorption or reactivation systems apart from the other treatment units also could not be identified.

Operation and Maintenance Costs

Operating and maintenance costs for the wastewater treatment systems including chemical treatment, dissolved gas flotation, filtration, sludge dewatering, adsorption, and granular carbon reactivation have averaged about $8,000/day. This amount does not include depreciation nor the cost of operating the dephenolizer and ammonia still.

Natural gas is used as fuel in the reactivation furnace, but fuel usage rates or cost of reactivation are not available.

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J.W. Schroeder, personal communication, September, 1979.

CASE HISTORY NO. 14
VILLAGE OF LEROY, NEW YORK
PHYSICAL-CHEMICAL WASTEWATER TREATMENT

HISTORY AND INTRODUCTION

In 1969, New York State's Division of Pure Waters advised the Village of LeRoy that it would be required to install tertiary treatment and disinfection if discharge was to continue in the vicinity of the existing primary effluent outfall.

Further, it was expected that such discharge would meet groundwater classifications and standards established by the Water Resources Commission. After several years of planning, and then delays while awaiting Federal funding, construction began in December, 1975.

The receiving water body for the wastewater from the Village of LeRoy in Oatka Creek, one of the finest trout fisheries in western New York. To protect this fishery, an extremely high degree of treatment was required. Detailed analysis determined that the point of discharge was critical. The treatment required for adequate stream protection was complete wastewater renovation. An extensive pilot plant demonstration program indicated the most economical solution was the use of a physical/chemical treatment process.

The selected major processes were:

1) Clariflocculation to remove gross solids, fine and colloidal solids, and phosphorus;

2) Rapid sand filtration to remove residual floc and solids to protect subsequent floc and solids to protect subsequent processes;

3) Activated charcoal absorption/adsorption to remove residual organics;

4) Breakpoint clorination, followed by activated carbon de-chlorination to remove ammonia.

These processes are supported by recarbonation of lime-softened water, final aeration, and on-site activated carbon regeneration. Figure A-29 is a flow schematic for the plant.

The control panel is designed so that major systems in the plant operate automatically and provides the operator with the necessary details to monitor the entire plant. The displays monitor the positions of critical valves and the condition of the primary elements of the process system. Automatic systems controlled by this panel are chemical feeds, backwashing of the sand filters and carbon columns, as well as the carbon transfer processes for regeneration.

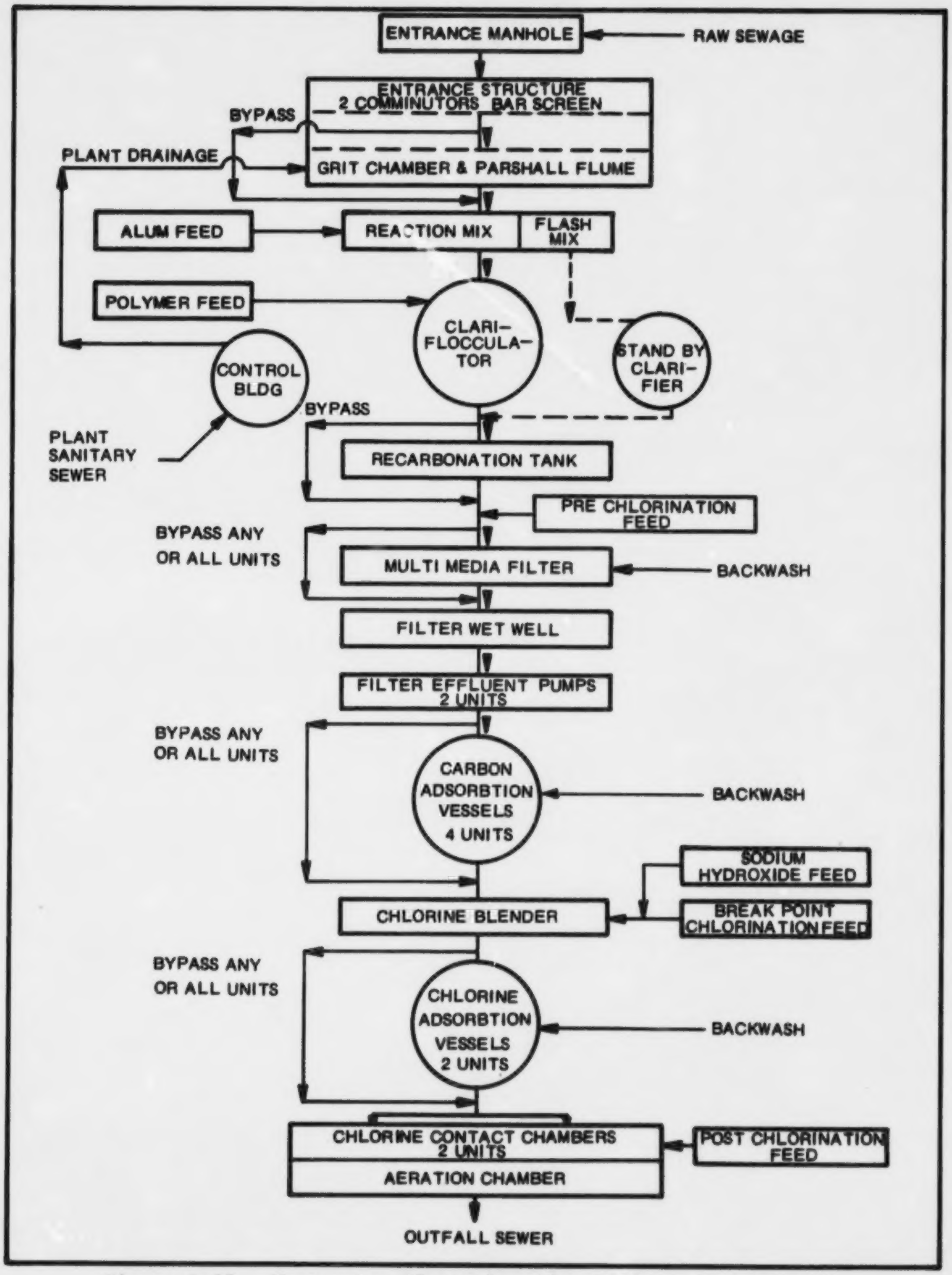

ENTRANCE MANHOLE
RAW SEWAGE
ENTRANCE STRUCTURE
2 COMMINUTORS BAR SCREEN
BYPASS
PLANT DRAINAGE
GRIT CHAMBER & PARSHALL FLUME
ALUM FEED
REACTION MIX
FLASH MIX
POLYMER FEED
CLARI-FLOCCULA-TOR
STAND BY CLARI-FIER
CONTROL BLDG
BYPASS
PLANT SANITARY SEWER
RECARBONATION TANK
PRE CHLORINATION FEED
BYPASS ANY OR ALL UNITS
MULTI MEDIA FILTER
BACKWASH
FILTER WET WELL
FILTER EFFLUENT PUMPS 2 UNITS
BYPASS ANY OR ALL UNITS
CARBON ADSORBTION VESSELS 4 UNITS
BACKWASH
SODIUM HYDROXIDE FEED
BREAK POINT CHLORINATION FEED
CHLORINE BLENDER
BYPASS ANY OR ALL UNITS
CHLORINE ADSORBTION VESSELS 2 UNITS
BACKWASH
CHLORINE CONTACT CHAMBERS 2 UNITS
POST CHLORINATION FEED
AERATION CHAMBER
OUTFALL SEWER

Figure A-29. Wastewater Flow Schematic, Village of LeRoy, NY.

The control panel has various alarms that notify the operator of system malfunctions and provide for manual override should the automatic mode fail.

GRANULAR ACTIVATED CARBON DESIGN DATA

Design capacity of GAC system	One mgd
Average flow through GAC system	0.450 mgd

System Configuration

Adsorption	
Number of contactors	Four
Vol. per contactor	1285 ft^3
Diameter of contactors	11 ft
Empty bed contact time	12 min
Reactivation	
Type of furnace	Fully automatic multi-hearth
Furnace size--physical description	
Number of hearths	Five
Diameter	9-ft 3-in., O.D.
Length	24-ft, 3 1/4-in., overall 13-ft, 6 1/2-in., shell
Frequency of reactivation	Quarterly
Activated carbon loss	8.5 percent
Loss in adsorptive capacity per reactivation cycle	Unknown
Furnace capacity	11,376 lb/day
Average furnace throughput	12,000 lb/day

Figure A-30 is a cross-section through a carbon contactor.

PLANT PERFORMANCE

There is very little experience, particularly with regard to costs, in operation of the plant. Plant operation has been intermittent and plagued with mechanical problems and problems of waste septicity. By November, 1979, most of the mechanical problems of the carbon adsorption system and carbon reactivation system had been corrected. Some mechanical difficulties with the lime slaker remained, and breakpoint chlorination treatment had not yet been practiced.

The principal remaining roadblock to full plant operation and anticipated plant performance is septicity. The raw sewage is septic when it enters the plant and remains septic throughout all of the treatment processes. Since the plant is a physical-chemical treatment operation, the facilities installed to correct septicity are rather limited. Until aerobic conditions can be established in the carbon columns, the results of adsorption treatment are likely to remain unsatisfactory and excessive reactivation of carbon will be needed.

Meaningful data on carbon system operations and costs cannot be obtained until the pretreatment process and mechanical problems are corrected.

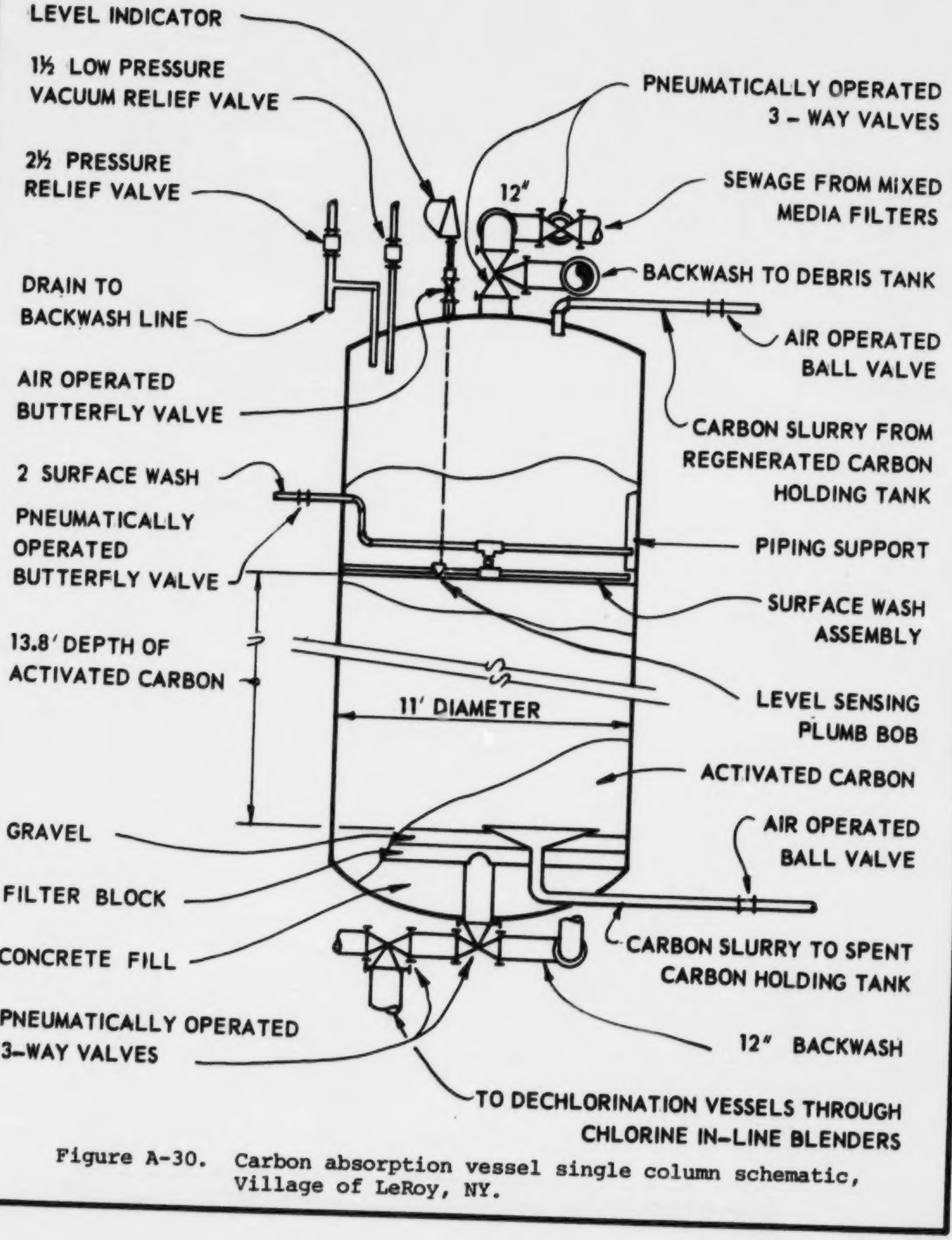

LEVEL INDICATOR
1½ LOW PRESSURE VACUUM RELIEF VALVE
2½ PRESSURE RELIEF VALVE
DRAIN TO BACKWASH LINE
AIR OPERATED BUTTERFLY VALVE
2 SURFACE WASH
PNEUMATICALLY OPERATED BUTTERFLY VALVE
13.8′ DEPTH OF ACTIVATED CARBON
GRAVEL
FILTER BLOCK
CONCRETE FILL
PNEUMATICALLY OPERATED 3-WAY VALVES
PNEUMATICALLY OPERATED 3 – WAY VALVES
12″
SEWAGE FROM MIXED MEDIA FILTERS
BACKWASH TO DEBRIS TANK
AIR OPERATED BALL VALVE
CARBON SLURRY FROM REGENERATED CARBON HOLDING TANK
PIPING SUPPORT
SURFACE WASH ASSEMBLY
LEVEL SENSING PLUMB BOB
11′ DIAMETER
ACTIVATED CARBON
AIR OPERATED BALL VALVE
CARBON SLURRY TO SPENT CARBON HOLDING TANK
12″ BACKWASH
TO DECHLORINATION VESSELS THROUGH CHLORINE IN-LINE BLENDERS

Figure A-30. Carbon absorption vessel single column schematic, Village of LeRoy, NY.

CAPITAL AND OPERATION AND MAINTENANCE COSTS

Capital Cost (1975)

Total system cost for piping, pumping, surge tanks, adsorbers, and reactivation furnace	$2,500,000
Amortization period	40 years
Interest rate	5 percent

Adsorption Operation and Maintenance Costs (1979)

Operations and maintenance labor	
Number of persons employed	Six
Number of hours worked per year	14,350 hr
Average wage rate	$6.60/hr plus benefits
Electricity	82,080 kwh/mo
Unit cost	$0.0394/kwh
Maintenance materials	Unknown--system still belongs to Contractor

Regeneration Capital and Operating Costs (1979)

Capital cost	
Furnace cost	Included in figures above
Operating cost	
Operations Labor	
Number of persons employed	Four
Total hours	6,000 hr/yr
Average wage rate	$6.74/hr plus benefits
Maintenance labor	
Number of persons employed	One
Number of hours worked per year	100 hr
Average wage rate	$6.35/hr plus benefits
Electricity	103,000 kwh/yr (estimated)
Total annual cost	$4,058
Unit cost	$0.0394/kwh
Fuel	
Type of fuel used	#2 Fuel oil
Total annual cost	$18,900
Quantity	30,000 gal/yr
Unit cost	$0.63/gal
Maintenance materials	None yet--have not accepted furnace from the Contractor
Carbon	
Total initial volume	7,500 ft^3
Makeup	68,000 lb/yr (estimated)
Unit cost	$68.36/cwt

CASE HISTORY NO. 15
CITY OF MANCHESTER, NEW HAMPSHIRE
PUBLIC WATER SUPPLY

HISTORY AND INTRODUCTION

Manchester, New Hampshire, is a city greatly concerned about its future growth and prosperity. While promoting economic expansion and residential growth, Manchester is actively preparing to accommodate the needs posed by this development. One step in this direction has already been taken--that of providing a safe, sufficient water supply for public and commercial consumption.

For more than a century, Lake Massabesic has served as the water supply for Manchester. When pollution for a growing population and industry jeopardized other domestic water supplies, Lake Massabesic--because of its natural characteristics and the constant efforts of the Manchester Water Works to safeguard its watershed--continued to supply the City with good quality water.

In recent years, however, Lake Massabesic water has been plagued by excessive color and severe periodic taste and odor caused by aquatic organisms. Oil and chemical spills caused by tanker trucks, which must pass over a narrow neck between the front and back ponds of Massabesic while traveling on the Route 28 Bypass, could contaminate the entire water supply. Projections for future water consumption indicate that, by the mid 1980's, Lake Massabesic will no longer be able to satisfy Manchester's average daily consumer demand. The poor quality water from the Merrimack River, now planned to supplement the Messabesic supply, will definitely require treatment.

These factors prompted the Manchester Board of Mayor and Aldermen to authorize the Board of Water Commissioners in May, 1970, to file an application for a federal grant to help finance the construction of a new water treatment plant. A few months later, the Department of Housing and Urban Development approved a $1,500,000 grant for this project. The Manchester Water Works then engaged consulting engineers to work with department engineers on the design of a water filtration plant capable of treating an average capacity of 30 mgd (maximum 40 mgd) to be built adjacent to Lake Massabesic.

Facility Planning and Testing

During the following months, the Water Works staff, assisting the consultants, undertook a comprehensive series of engineernig evaluations in such areas as filtration, standby power, treatment systems, and chlorine generation before formulating a facility that would incorporate the most innovative concepts and sophisticated techniques in the field of water treatment.

An extensive predesign study included comprehensive raw water analysis and testing; evaluation of alternate treatment techniques in view of their efficiency, operating costs, and initial construction costs, and model testing. This study revealed that complete conventional pretreatment including flash mixing, flocculation, and sedimentation must be undertaken before filtration.

Treatment for the first 10 years of operation would concentrate on removing raw water color and controlling periodic taste and odor. Removing volatile organics, turbidity, and other contaminants from Merrimack water would be done in the future. Initially, powdered activated carbon was considered to remove taste, odor, and other volatile organics, but because of the unpredictability of the treatment process, continuous filtration through GAC was chosen to guarantee reliable performance.

To ensure maximum use and life of the activated carbon, the carbon filters were designed to operate in series with the sand filters. This arrangement permits sand filters to remove all pinpoint floc and other particulate matter remaining in the settled water; the carbon filters serve only to absorb organic compounds. A basic flow schematic of the processes used at Manchester is given on Figure A-31.

DESIGN AND OPERATION

Basis of GAC System Design

The Manchester facility is the first water purification plant in the country to be designed for series sand and carbon filtration. Both the sand and carbon filters are automatic backwash filters (ABW). ABW filters need not be removed from service for backwashing. Each filter consists of several independent cells that can be isolated individually and backwashed while the remaining cells continue to process the water.

Backwashing is accomplished in the same way for both sand and carbon filters. A carriage mechanism that spans the width of the filter travels about 2 ft/min across the bed. Water is pumped beneath a single cell, up through the sand to the backwash hood, and into the washwater pump for disposal in the washwater launder located along the filter wall. After filtration, water flows into a clearwell located beneath the finish water pump room from which water will be pumped into the distribution system. Backwash water from the sand filters flows by gravity into three sludge settling lagoons outside the plant. Filter backwash water and carbon transport water are recycled to the headworks of the water treatment plant.

The following are the design data for the system

Filtration and GAC adsorption

Number of sand filters	Four
Number of carbon filters	Four
Filter surface loading at 30 mgd	2.96 gpm/ft^2
Sand media size	0.60-0.65 mm
Sand media depth	11 in.
Carbon media size	8 x 30 mesh

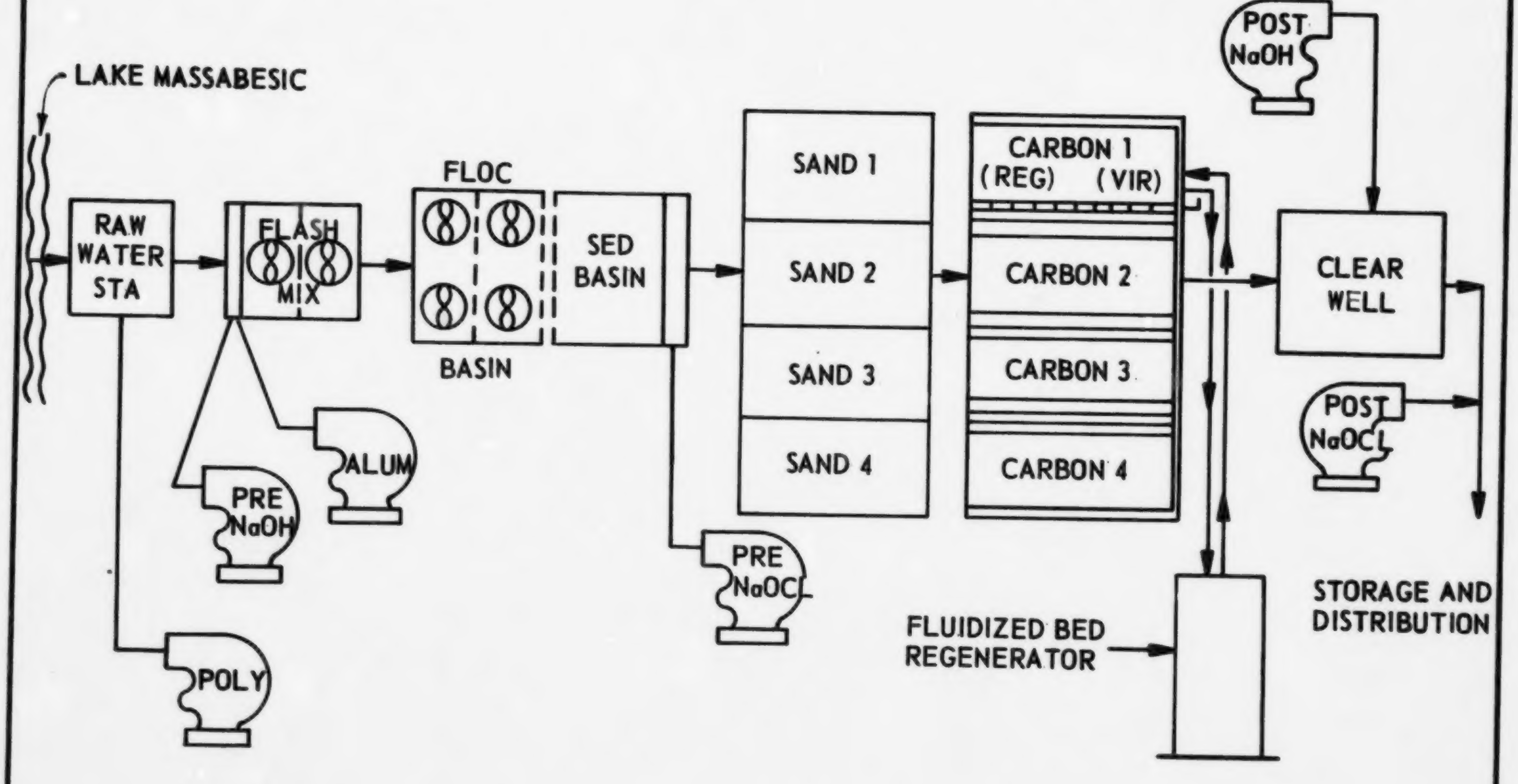

LAKE MASSABESIC
RAW WATER STA
FLASH MIX
FLOC
BASIN
SED BASIN
PRE NaOH
ALUM
POLY
PRE NaOCL
SAND 1
SAND 2
SAND 3
SAND 4
CARBON 1
(REG)
(VIR)
CARBON 2
CARBON 3
CARBON 4
FLUIDIZED BED REGENERATOR
POST NaOH
CLEAR WELL
POST NaOCL
STORAGE AND DISTRIBUTION

Figure A-31. Regeneration and treatment schematic, Manchester, NH.

Carbon media depth	48 in.
Clearwell volume	400,000 gal

GAC System Operation

The Manchester Water Treatment Plant features conventional chemical pretreatment, coagulation, flocculation, and sedimentation, followed by series filtration through four, 11-in. deep rapid sand filters and four, 48-in. deep GAC filters. The sand filters serve to remove floc carryover and other particulates that might tend to interfere with adsorption and thereby reduce GAC life expectancy. All eight of the filters have a maximum design surface loading rate of 4.0 gpm ft^2 and are presently operated in series at a rate of about 1.3 gpm/ft^2 and empty bed contact time (GAC filters only) ranging from 14 to 22 min. The carbon itself is of coal base origin having been used successfully for the continuous removal of tastes and odors due to algae since startup of the treatment plant in November, 1974.

Briefly, the cycle that the carbon will pass through in going from the filters to the regeneration building and then back to the filters is described as follows. First, the GAC will be hydraulically educted from each filter and directed to a spent carbon storage tank located in the regeneration building. At this point, it is then passed through a dewatering and metering screw and then fed to the upper drying stage of the regenerator described earlier. Once the carbon passes through the regenerator and exists at the bottom of the furnace, it will be placed into a quench tank for cooling and then into a regenerated carbon storage tank for subsequent return to the filters via water jet eductors.

Reactivation of GAC

In light of the recent EPA regulations for trihalomethanes (THM) and for carbon treatment, water utilities will more commonly use GAC. In the past, the use of carbon in water treatment has been minimal; the cost for using it on a throw-away basis has been moderate. Recently, faced with using large quantities of carbon at ever-increasing costs, certain water utilities have begun using on-site reactivation systems.

Manchester has installed a WESTVACO fluidized bed furnace to reactivate the spent carbon from its GAC system (Figure A-33). EPA sponsored the initial operation and testing of this system.

The WESTVACO fluidized bed design operates on a two-stage approach (illustrated on Figure A-33); the wet spent carbon is dried in the upper stage of the furnace using the off-gas from the lower regeneration stage as the primary heat source. In the drying zone, a small amount of the organics may be volatized from the carbon, but the majority remain adsorbed on the carbon and pass to the lower regeneration zone. In this area, part of the adsorbates are volatized from the carbon and the remaining pyrolyzed portion is removed by selective reaction with steam until complete regeneration is achieved. Volatile adsorbates are combusted in the incineration zone above the regeneration bed while the off-gas is passed through an air scrubber where carbon dust is removed.

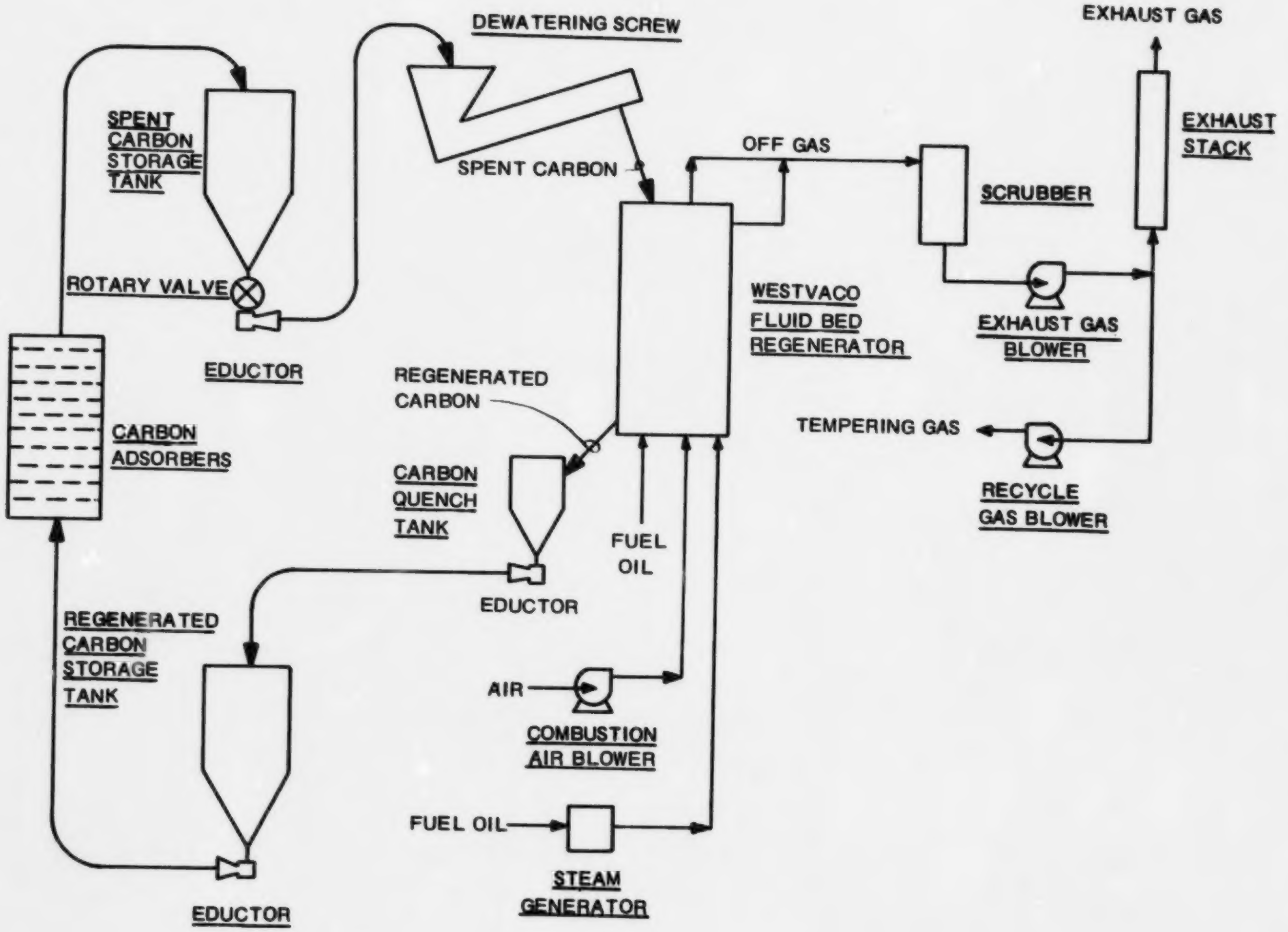
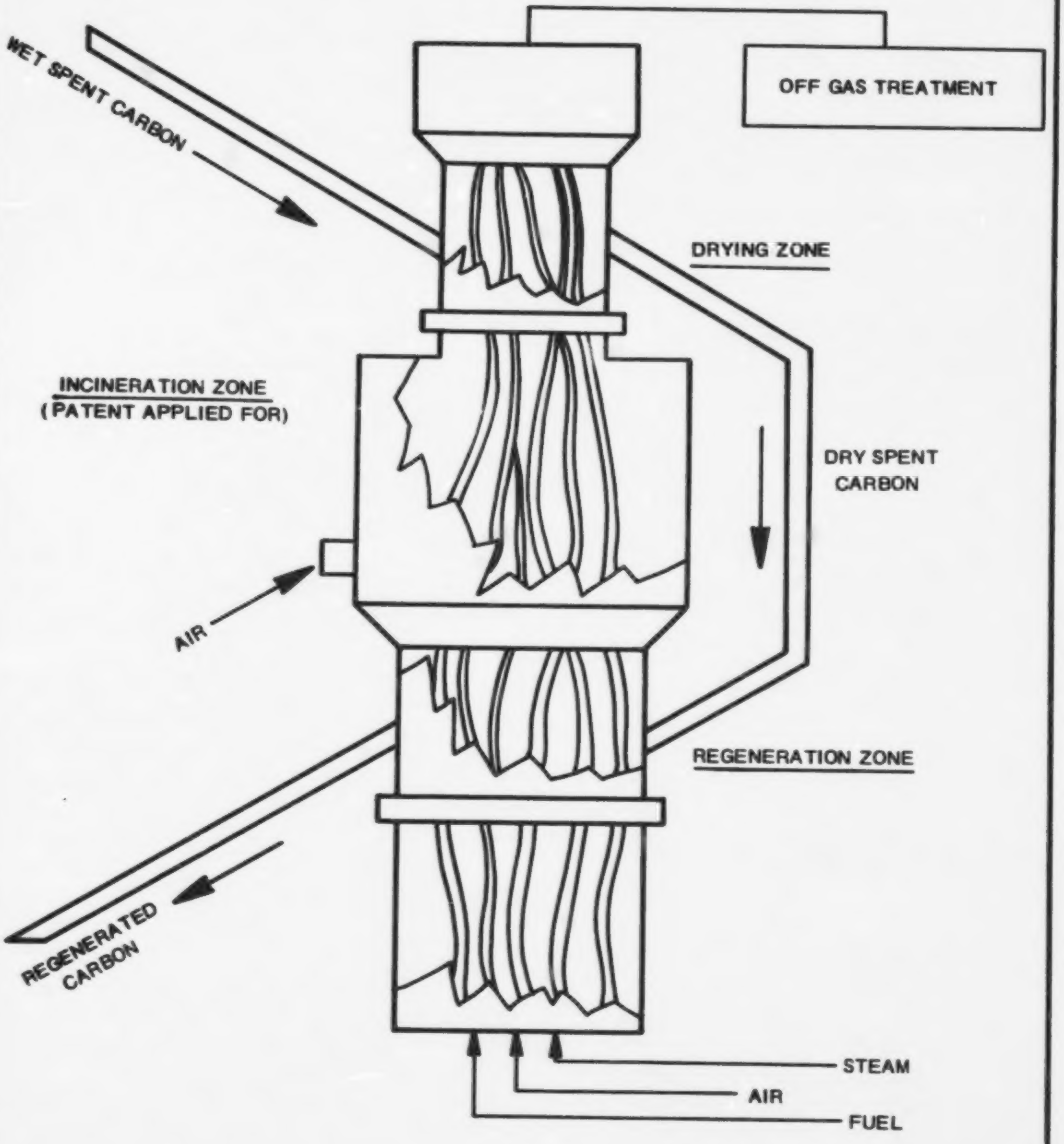

DEWATERING SCREW
EXHAUST GAS
SPENT CARBON STORAGE TANK
SPENT CARBON
OFF GAS
EXHAUST STACK
SCRUBBER
ROTARY VALVE
WESTVACO FLUID BED REGENERATOR
EXHAUST GAS BLOWER
EDUCTOR
REGENERATED CARBON
TEMPERING GAS
CARBON ADSORBERS
CARBON QUENCH TANK
RECYCLE GAS BLOWER
FUEL OIL
EDUCTOR
REGENERATED CARBON STORAGE TANK
AIR
COMBUSTION AIR BLOWER
FUEL OIL
STEAM GENERATOR
EDUCTOR

Figure A-32. Process flow for activated carbon regeneration system, Manchester, NH.



WET SPENT CARBON
OFF GAS TREATMENT
DRYING ZONE
INCINERATION ZONE
(PATENT APPLIED FOR)
DRY SPENT CARBON
AIR
REGENERATION ZONE
REGENERATED CARBON
STEAM
AIR
FUEL

Figure A-33. WESTVACO fluidized bed furnace for reactivating spent carbon.

Reported operating advantages of this type of system include better fuel economy and no internal moving parts, which may result in less maintenance and lower costs.

The fluid bed regeneration system now installed at Manchester has a design operating capacity of 12,000 lb/day (500 lb/hr) of regenerated carbon and a projected estimated total operating cost of 8.9¢/lb for 1979 (Table A-35). Construction work on the system began in early August, 1978 and was completed in early 1979 at a cost of about $785,000. This figure includes the cost of furnishing and installing the furnace, the cost of a 34 ft x 39 ft x 30 ft high building to house the furnace, and the cost of a new semi-automatic carbon handling system. About 60 percent of the total project cost is being funded under a Safe Drinking Water Act research grant awarded by EPA.

The research objectives of this project will be to evaluate both the cost and performance of a GAC regeneration system utilizing fluid bed principles, the cost and capabilities of a new system for handling carbon, plus the adsorptive effectiveness of both virgin carbon and regenerated carbon for removal of chlorinated organics and their precursors from drinking water. Research work began in late 1979 and is to continue over a 17- to 24-month period.

CAPITAL AND OPERATION AND MAINTENANCE COSTS

Table A-36 summarizes the direct and indirect capital costs and the construction costs for the fluid bed GAC reactivation furnace at Manchester. Operation of this facility has just started, and no actual operating cost data are yet available.

TABLE A-35. SUMMARY OF ESTIMATED* DIRECT AND INDIRECT COSTS FOR OPERATION OF FLUID BED REGENERATION SYSTEM MANCHESTER, NH

Item	Year	Month	Day	lb GAC
Direct costs				
Makeup carbon (1)†	$210,000	$17,500	$600.00	$0.0500
Labor (2)	20,800	1,733	59.43	0.0049
Maintenance and repairs (3)	13,608	1,134	38.88	0.0032
Fuel (4)	58,800	4,900	168.00	0.0140
Power (5)	8,820	735	25.20	0.0021
Water (6)	8,142	679	23.26	0.0019
Total	$320,170	$26,681	$915.77	$0.0761
Indirect costs				
Depreciation (7)	$ 43,750	$ 3,646	$125.00	$0.0104
Insurance (8)	695	58	1.98	0.0002
Administration and overhead (8)	8,950	729	25.00	0.0021
Total	$ 53,195	$ 4,433	$152.00	$0.0127
Total direct and indirect costs				
Total	$373,365	$ 31,114§	$7,068.00	$0.0890

*Estimate is based on steady state operation, 350 days/yr. Actual costs of fuel, power, and labor are expected to rise above figures shown.

†Cost components

(1) 10 percent loss, $0.50/lb GAC
(2) 24 operator hr/day, $208/wk/oper
(3) 3 percent of equipment cost/yr
(4) 10 gal/hr fuel consumption, $0.70/gal fuel cost (for regenerator and steam boiler)
(5) 0.06 kw/lb GAC 3 1/2/2¢/kwh
(6) 10.8 gal/lb GAC, $174.49/mil gal
(7) 20 yr dep. by straight line method
(8) Actual premium for added coverage

§Monthly estimated operating cost less depreciation is $27,468

TABLE A-36. SUMMARY OF FINAL CONSTRUCTION COSTS FOR PHASE ONE OF CARBON REGENERATION PROJECT - MANCHESTER, NH PROJECT, EPA GRANT R8057371

Item Number	Construction	Amount
1.	Carbon regeneration building (34 ft x 39 ft x 30 ft high)	$226,852
2.	Fluid bed carbon regeneration system (capacity - 6 ton/day)	528,630
3.	Semi-automatic carbon transport system (4 filters)	120,517
4.	Miscellaneous costs	6,407
5.	Total construction cost	$882,406*

*Total cost of Item 7 of Financial Report to EPA, September, 1979. The above costs have been reported to and are currently being reviewed by the EPA and are not to be published without the prior written approval of the EPA Project Officer.

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A visit to the Manchester Water Treatment Plant in October, 1979, and a discussion with David Kittredge and other Department staff members.

CASE HISTORY NO. 16
PASSAIC VALLEY WATER COMMISSION
LITTLE FALLS WATER TREATMENT PLANT
CLIFTON, NEW JERSEY
MUNICIPAL WATER TREATMENT

HISTORY AND INTRODUCTION

The Little Falls Filtration Plant of the Passaic Valley Water Commission is located on the Passaic River near Towata, New Jersey. The Passaic River, which is the source of supply, is a highly polluted stream that receives industrial wastes from hundreds of upstream discharges. Organics have long been a problem and GAC has been used experimentally for adsorption of organics.

Because of the organics problems and the local interest in their control, the Little Falls Plant was one selected by EPA to study various methods for reactivation of GAC that has been saturated with organics adsorbed from drinking water.

The infrared electric furnace is the thermal reactivation equipment to be evaluated at Little Falls. The potential advantages of this method are: (1) the general availability of electric power as compared with the fossil fuels required by other types of furnaces, (2) shorter warm-up and cool-down periods as compared with alternative equipment, and (3) lower attrition of carbon on the traveling belt used in the electric furnace as compared with attrition losses in furnaces involving movement of the carbon by rabbling or fluidizing.

GAC REACTIVATION SYSTEM

The Little Falls Filtration Plant employs prechlorination, alum coagulation, settling, dual-media (anthracite coal over sand) filtration, and, at times, dechlorination. The average flow is 55 mgd. A side stream of filtered water (2.2 mgd) is diverted to three pressure vessels each containing a different type granular activated carbon with an empty bed contact time (EBCT) of approximately 8 min.

GAC Reactivation Furnace Design

The furnace being evaluated is a 100 kw, 100 lb/hr infrared tunnel unit manufactured by Shirco, Inc. of Dallas, Texas, with the following characteristics (see Figure A-34).

Dimensions	4-ft wide x 20-ft long
Activated carbon residency time	20 to 25 min
Temperature	
Drying zone	1150°F
Activation zone	1650°F
Warm-up time	30 min
Weight	17,000 lb

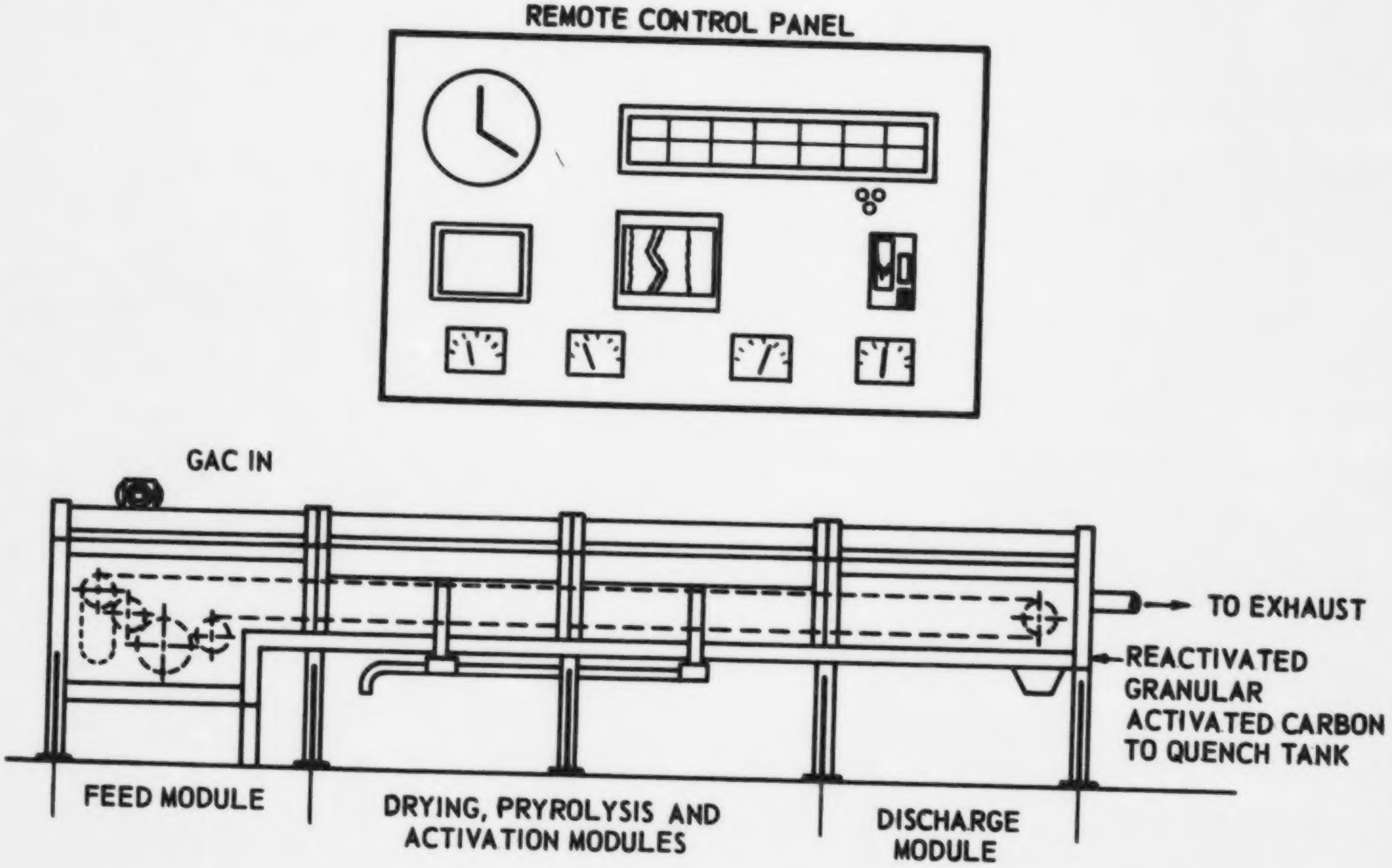
REMOTE CONTROL PANEL
GAC IN
TO EXHAUST
REACTIVATED GRANULAR ACTIVATED CARBON TO QUENCH TANK
FEED MODULE
DRYING, PRYROLYSIS AND ACTIVATION MODULES
DISCHARGE MODULE

Figure A-34. Cross section of infrared tunnel furnace, Little Falls Water Treatment Plant, Clifton, NJ.

OPERATION AND PERFORMANCE

The GAC adsorbers became operational in March, 1978 and carbon was exposed continuously (without backwash) for 3 months. The adsorbents were then sequentially educted into a storage bin, fed into the furnace, then returned to the adsorbers for quenching. By May, 1979, the granular carbon had been reactivated twice and plans were to have at least two more exposure/reactivation cycles before the project was completed.

For the initial reactivation, the contact time for the granular carbon within the furnace was 20 min at a temperature of 1650°F. These conditions were selected by the furnace vendor on the basis of thermographic analysis and iodine numbers.

The first carbon to be reactivated in this system was the lignite base HD-1030 (a product of ICI Americas, Inc.). Unfortunately, because of inexperience, problems in handling the adsorbent and in the operation of the furnace occurred, and excessive atypical losses resulted. Further, performance of the lignite activated carbon could not be equitably judged. The characteristics of the two coal-based granular carbons (WESTVACO WV-W and Calgon F-400) before and after reactivation are shown in Table A-37. Iodine numbers were restored to within 12 percent of the virgin granular carbon, and apparent densities increased about 3 percent through the cycle.

TABLE A-37. COMPARISON OF VIRGIN TO REACTIVATED GRANULAR CARBON, CYCLE 1

Granular carbon	Carbon Virgin	 Exhausted	 Reactivated
Iodine number			
HD-1030	601	416	(See text)
WV-W	850	711	761
F-400	1023	790	890
Apparent density			
HD-1030	0.44	0.44	(See text)
WV-W	0.57	0.61	0.57
F-400	0.47	0.51	0.49

The real test, of course, was how the GAC performed on the actual treated Passaic River water. The total organic carbon (TOC) concentration in the influent to the virgin activated carbon ranged from 1.5 mg/L to 3.9 mg/L, with a mean of 2.7 mg/L. When the adsorbents were reactivated and put back into service, the TOC had a mean concentration of 4.4 mg/L. Because of the different loadings, comparison of virgin to reactivated carbon is difficult, but if these differences are neglected, the decline in TOC removal is approximately 12 percent for the 11 weeks in service after reactivation (see Figure A-35). Subsequent cycles should allow for more direct comparisons.

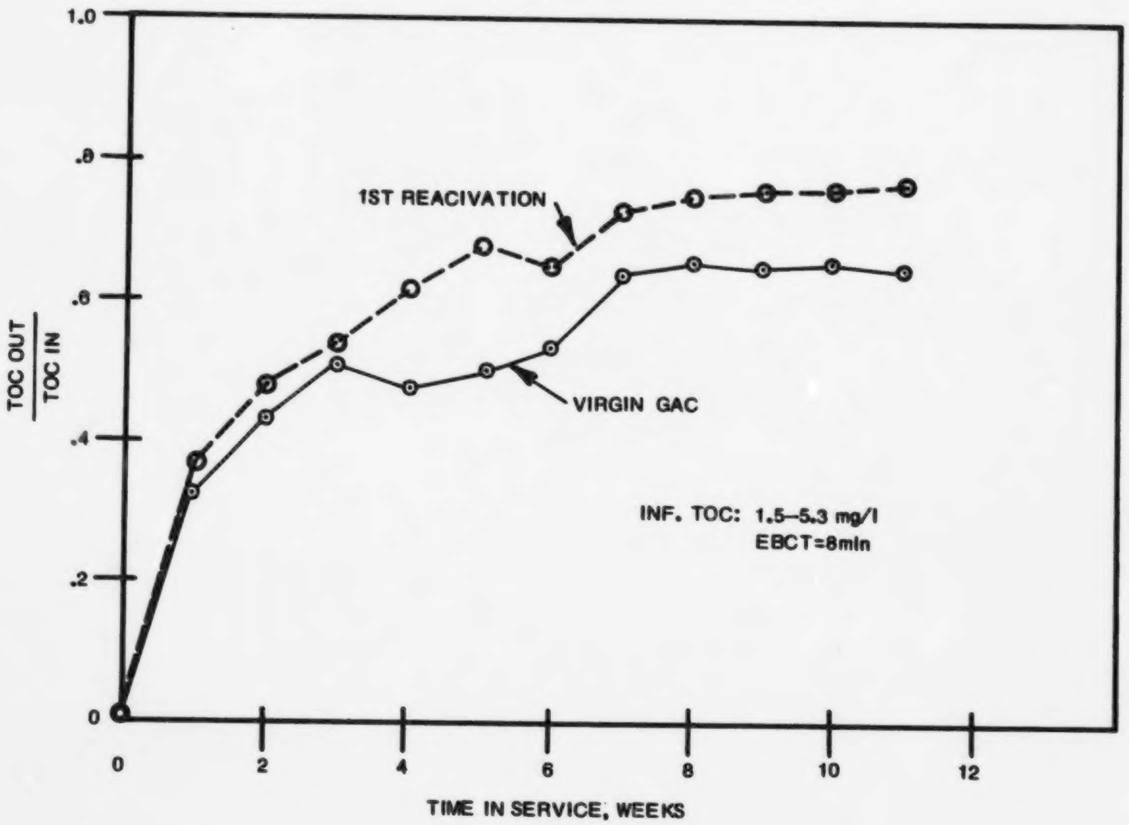

Figure A-35. Effectiveness of reactivation measured by total organic carbon.

Organic halogen (TOX) concentrations on samples of activated carbon collected from the top and bottom of each adsorber were averaged and the results shown in Figure A-36. Again, the reactivated carbon was about 10 percent less effective than the virgin material. Because of a modification in the TOX analysis, the influent and effluent TOX concentrations before and after reactivation cannot be compared directly. For perspective, however, the nonpurgeable organic halogen concentrations applied to the adsorbents after reactivation ranged from 106 g/L to 260 g/L, and the breakthrough pattern was very similar to the TOC curve.

Although both UV absorbance and fluorescence data were collected, the latter parameter is more consistent and is potentially a good operational monitor for this system. Figure A-37, a plot of fractional removal of fluorescence, shows about 4 percent difference between virgin and reactivated granular carbon.

In the adsorption of organics from highly treated municipal wastewater at South Tahoe and Orange County (Water Factory 21), the apparent loss in GAC adsorptive capacity during the first regeneration as measured by the iodine number was 10 to 15 percent, but there was no observed loss in capacity to remove COD. After the initial regeneration at these two locations, there was no further decline in iodine numbers. At South Tahoe, where GAC has been in service for 11 years, the carbon has been through a full 20 cycles of reactivation.

Discussion of Results

The study by the Passaic Valley Water Commission at the Little Falls Filtration Plant is providing very useful information for understanding the handling and reactivating of granular carbon. The infrared furnace in the first reactivation restored the adsorptive properties (depending on which parameter performance is judged on) to within 85 to 96 percent of virgin.

The second reactivation was completed, and in May, 1979, twice reactivated carbon was being exposed to filtered water. Furnace conditions were changed slightly for the second reactivation. The temperature in the activation zone was raised to 1700°F and the retention time lengthened to 25 minutes. The iodine numbers and apparent densities improved and, when compared with the first reactivation, these preliminary indications are encouraging that other removal parameters such as TOC and TOX will also improve.

Improvement in iodine numbers and apparent densities of the GAC obtained by use of higher reactivation temperatures and more time in the furnace may be accompanied by higher carbon losses due to burning. Experience with reactivation of GAC in food processing plants and in wastewater treatment has shown that it is possible to strike a satisfactory economic balance between burning losses and restoration of carbon activity by proper manipulation of furnace temperatures and retention time. In these applications, the optimum carbon loss per cycle (total attrition and burning loss) is usually in the 8 to 10 percent range.

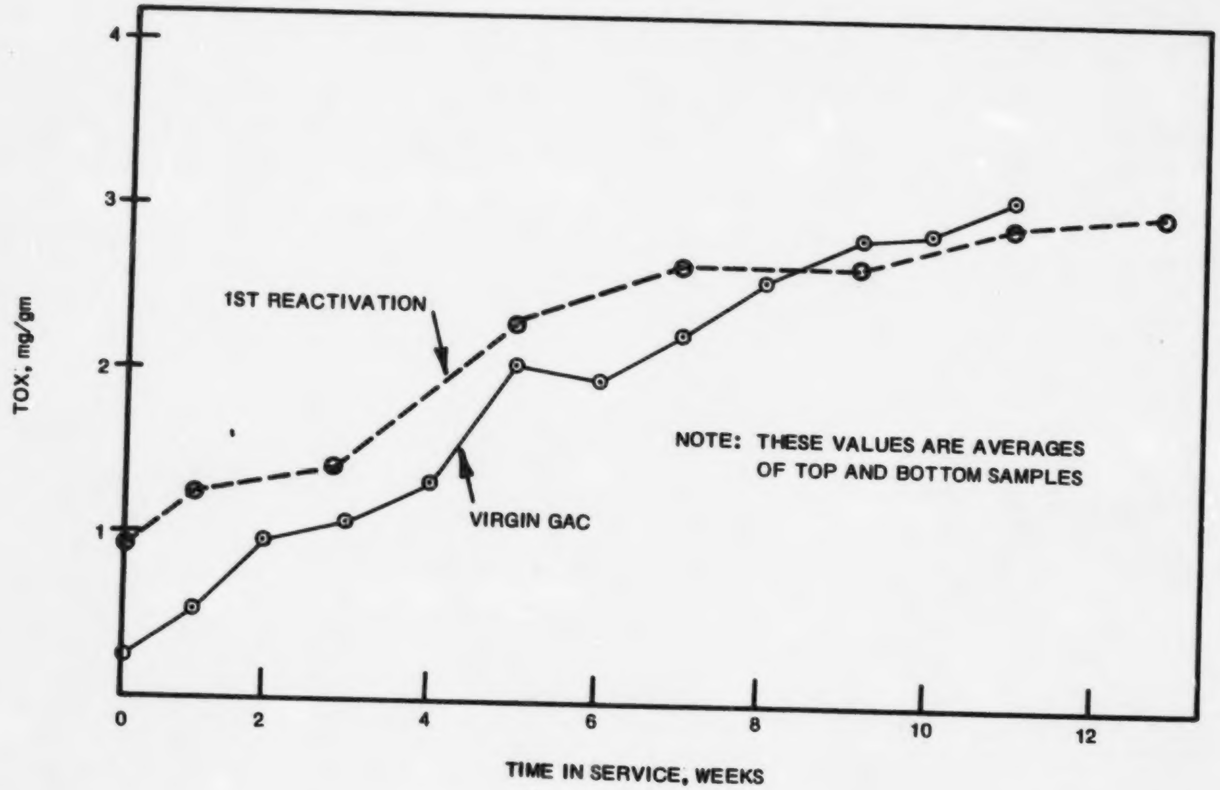

Figure A-36. Effectiveness of reactivation measured by total organic halogen.

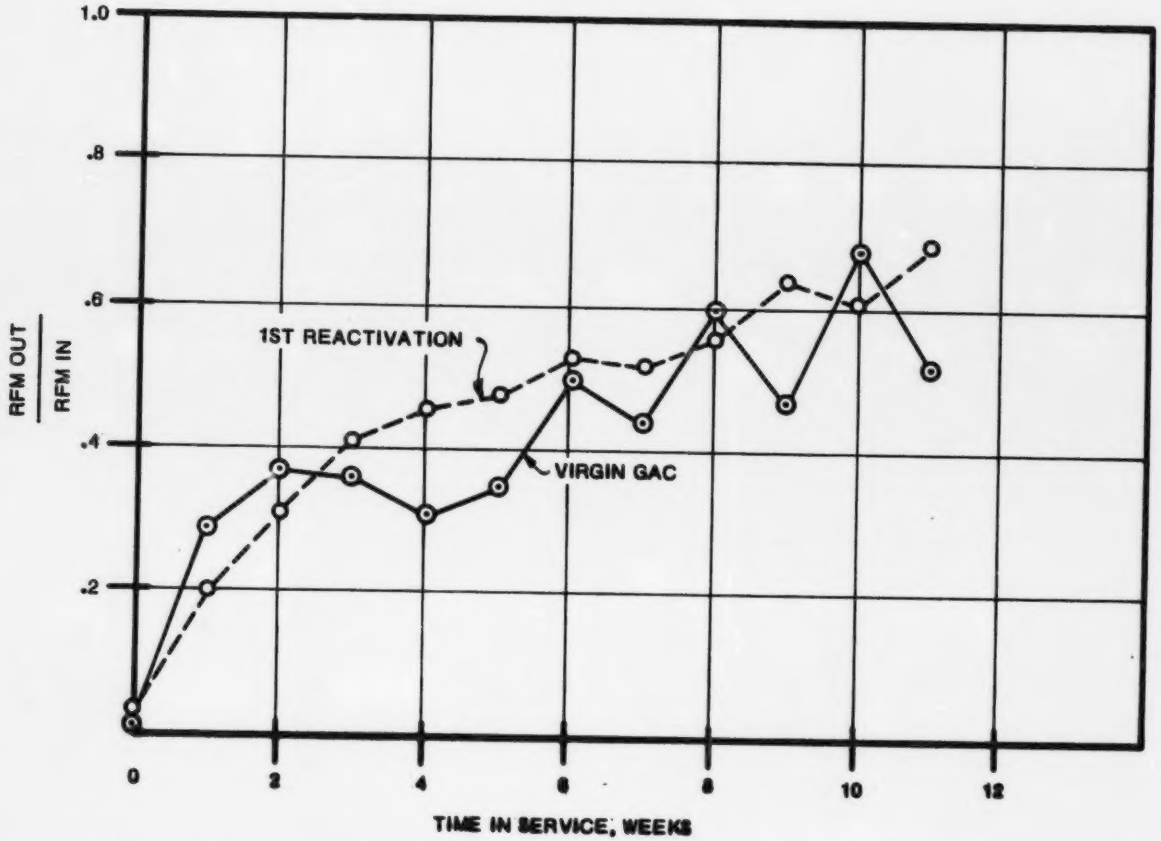

Figure A-37. Effectiveness of reactivation measured by fluorescence.

Operational Problems

The methods used to transfer the exhausted carbon from the adsorbers to the storage hopper are unsatisfactory. The greatest deficiency, however, lies in the inability to feed spent carbon to the furnace at a uniform metered rate. The present system for doing this is totally unsatisfactory. Carbon is fed to the furnace at an unknown, highly variable rate. Further, the method of dewatering the carbon results in a highly variable moisture content in carbon fed to the furnace. It is surprising that the furnace has worked as well as it has considering that the layer of carbon on the furnace belt is of nonuniform thickness and with a variable moisture content. The furnace cannot possibly operate at reasonable efficiency under these conditions. A fair assessment of furnace capabilities can only be made if the present facilities for dewatering and feeding the carbon to the furnace are completely replaced with a satisfactory system.

Severe corrosion problems have been experienced in exhaust gas scrubbers. There are two potential corrective measures: the pH of the scrubber water may be elevated by adding sodium hydroxide, or the scrubber may be fabricated entirely of 316 SS.

SUMMARY

Despite the problems experienced, the performance of the electric furnace at Little Falls is very encouraging. The problems encountered are mechanical in nature and are not GAC process problems.

Information available on the operation of this unit in May, 1979 is summarized in Table A-38. Preliminary indications are that the second reactivation is improved from the first. Separating burning losses from attrition losses is not possible, and the losses shown are aggregates. These losses can perhaps be reduced as more experience is gathered in operating the system. The power requirements are reassuring. Assuming a power cost of \$0.03/kwh, the cost of running the furnace would be slightly over 2¢/lb carbon reactivated. This compares very favorably with the reported power costs from installations using other type furnaces.

TABLE A-38. COMPARISON SUMMARY FOR VIRGIN AND REACTIVATED CARBON

Operation parameter	Cycle 1 Percent change	Cycle 2 Percent change
Iodine number	-12	-6
Apparent density	+ 3	+1
Total organic carbon	-11	Not yet available
Fluorscence	- 4	Not yet available
Total organic halogen	-10	Not yet available
Carbon losses*	7%	4%
Power required†	0.7 kw/lb	0.7 kw/lb (1.6 kw/kg)

*This is for the entire system--sum of losses from initial backwash through transporting, reactivation, and quenching.

†This is the electrical power for the furnace only.

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A visit to the Little Falls Water Treatment Plant in October, 1979.

CASE HISTORY NO. 17
COLORADO SPRINGS, COLORADO
MUNICIPAL WASTEWATER TREATMENT

HISTORY AND INTRODUCTION

This wastewater treatment facility is located in Colorado Springs, Colorado, and became operational in December, 1970. Two unique circumstances make this facility somewhat different from other plants. The tertiary treatment is preceded by bio-filtration, and the bio-filtration process was heavily overloaded during operation of the tertiary plant. The effluent from the heavily loaded secondary plant presented some difficult mechanical and operational problems in subsequent treatment.

The City of Colorado Springs constructed the Advanced Wastewater Treatment Plant with an EPA Research and Demonstration Grant. The total cost of the program was $1.0 million, with the EPA and the City of Colorado Springs each paying one half.

The tertiary plant consists of two "circuits", each involving different processes. These circuits are called the Irrigation and the Industrial. The completed plant was first put on-line in December, 1970. It operated continuously for 4 years and has been operated only intermittently since 1975.

- Irrigation Circuit consists of four dual-media pressure filters operated in parallel. The media is made up of 3 ft of 1.5 mm sand on the bottom and 5 ft on 2.8 mm Anthrafilt on the top. Each filter has a surface area of 113/ft^2. At a design loading of 15 gpm/ft^2, they produce a total of 9 mgd.

- Industrial Circuit (see Figure A-38) water receives a much higher degree of treatment than the Irrigation Circuit water. It has a design capacity of 2.0 mgd. The Industrial Circuit utilizes lime addition, recarbonation, filtration, and carbon adsorption. The plant also has lime recalcining and carbon reactivation facilities.

DESIGN DATA

Carbon Adsorption System Design and Operation

After filtration, the wastewater is passed through two down-flow carbon adsorption towers in series. These towers are 20-ft in diameter with a total side wall depth of 14 ft. There is a 10-ft deep bed of 8 x 30 mesh granular activated carbon in each tower. This amounts to 94,000 lb carbon/tower. At design flow of 2 mgd, the loading rate is 4.25 gpm/ft^2, giving a total residence time in the carbon beds of 34 min. Carbon loading is calculated on pounds of COD removed per pound of carbon (usually between 0.50 and 0.60).

The GAC used at Colorado Springs is WESTVACO WV-L 8 x 30. The Colorado Springs plant determines need for carbon reactivation by the carbon loading in terms of pounds of total COD removed per pound of carbon. Generally, the adsorption service cycle is stopped when a value of 0.45 to 0.60 is attained. The carbon tower is not removed from service when a certain COD, BOD, TOC, or MBAS breakthrough occurs, but rather when the desired carbon loading is reached. COD loadings in excess of 0.60 makes adequate regeneration more difficult, i.e., higher temperatures are required, slower carbon feed rates to the furnace are necessary, and longer time for reactivation results.

The average COD loading for 12 regeneration cycles has been 0.05 lb removed/lb carbon. The two-stage system involves changing columns from the "lead" to the "polish" position. It allows the carbon to adsorb 41 percent more COD loading. Fifty-eight percent of the total COD removal is accomplished when the tower is in the lead position, and the average lead position loading is 0.292 lb/lb carbon. The average polish position loading is 0.207 lb/lb carbon.

When the Colorado Springs tertiary plant operated under severe loading conditions because of the overloaded secondary trickling filters, frequent backwashing was necessary. Another reason for daily backwashing is because of the production of hydrogen sulfide. If the towers are allowed to become anaerobic, sulfates in the water are reduced to sulfides--creating severe odor problems. Both carbon towers were backwashed daily, as were the dual-media filters. To backwash, the tower is taken off-line, then backwashed with an air scour at 3.5 cfm/ft^2 for 15 min. This procedure is repeated two times per backwash and results in an average backwash water use of 10 percent, which is rather high. Ordinary operation should require backwashing only every other day.

Carbon losses were excessive when the carbon towers were backwashed at 20 gpm/ft^2 with a resulting bed expansion of 50 percent. The carbon towers have 14-ft side walls and 4-ft conical tops and were designed for a 10-ft depth of carbon. Because 2 ft of the total sidewall depth is occupied by the underdrains, a bed expansion of only 2 ft, or 20 percent, is permissible without loss of carbon. The space provided for carbon expansion is adequate to retain the carbon in the towers during backwashing.

The result was that much carbon was lost in the backwash system. Sometimes as much as 1 ft of carbon (9,400 lb) was lost during a few backwashing cycles. To avoid this, the designed 10-ft bed depth as reduced to 8 ft. This allows a 50 percent bed expansion within the tower, and practically eliminates carbon losses due to backwashing. Future plans include screening of tower outlets and allowance for 65 percent bed expansion. The capital cost of this increase will very quickly be paid for by reduced carbon losses.

Complete monitoring of backwash functions should not be overlooked. Accurate flow meters monitoring the rate of backwash water are of utmost importance. Colorado Springs uses air to scrub the carbon. Simultaneous air and water backwashing can be done only under close control and at very low rates. Using air and water together for backwashing is not recommended because carbon

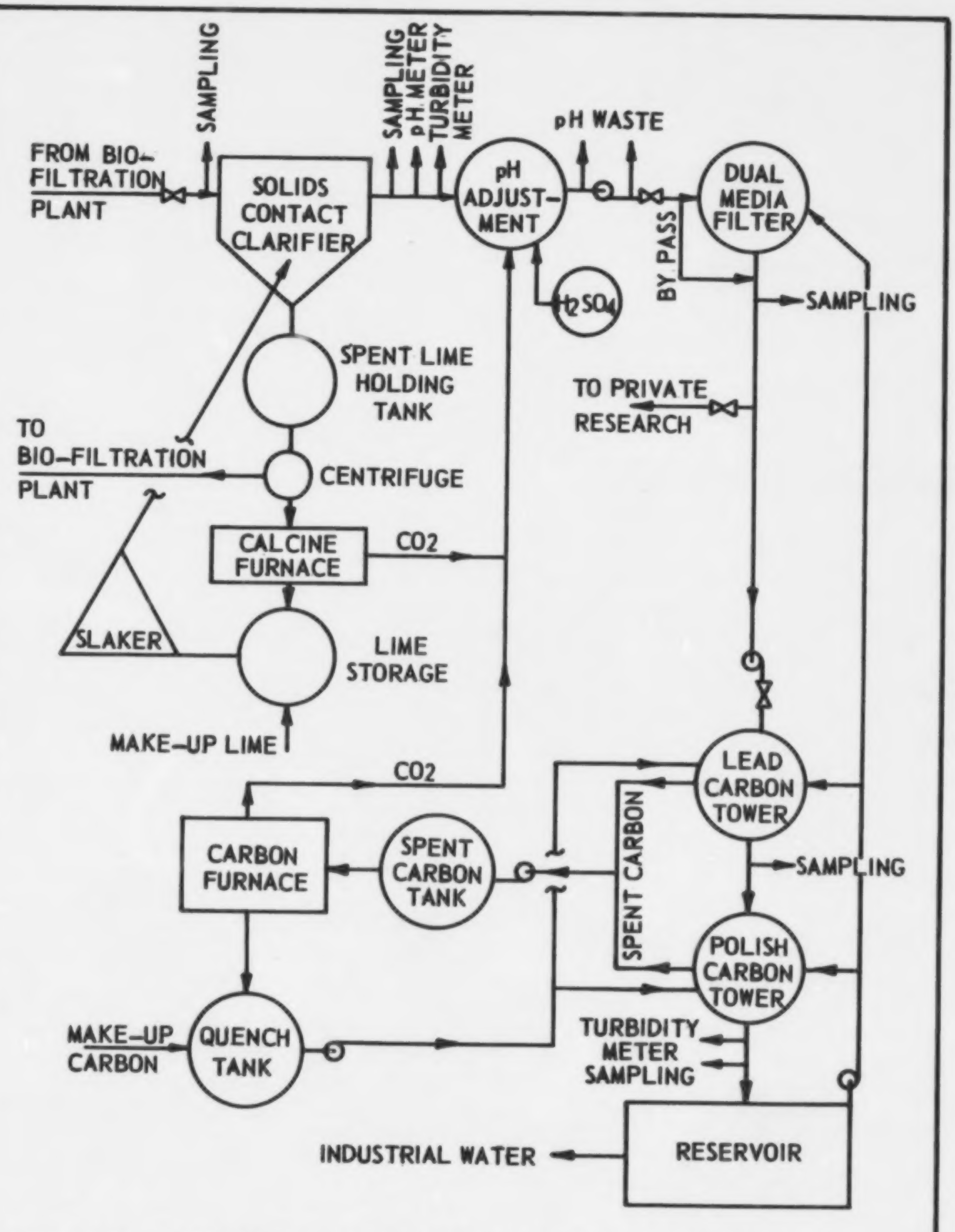
SAMPLING
SAMPLING
pH METER
TURBIDITY METER
pH WASTE
FROM BIO-FILTRATION PLANT
SOLIDS CONTACT CLARIFIER
pH ADJUSTMENT
DUAL MEDIA FILTER
BY PASS
H_2SO_4
SAMPLING
SPENT LIME HOLDING TANK
TO PRIVATE RESEARCH
TO BIO-FILTRATION PLANT
CENTRIFUGE
CALCINE FURNACE
CO2
SLAKER
LIME STORAGE
MAKE-UP LIME
CO2
LEAD CARBON TOWER
CARBON FURNACE
SPENT CARBON TANK
SPENT CARBON
SAMPLING
POLISH CARBON TOWER
MAKE-UP CARBON
QUENCH TANK
TURBIDITY METER
SAMPLING
INDUSTRIAL WATER
RESERVOIR

Figure A-38. Flow diagram of the industrial circuit, Colorado Springs, CO.

loss will be severe and there is very little improvement over using the alternating air-water cycle procedure.

Carbon Reactivation System Design and Operation

When the carbon in a tower has become exhausted, the carbon is conveyed by a water eductor, to a spent carbon holding tank. The carbon is removed from the holding tank through a rotary proportioning valve to eductors and then fed by a dewatering screw to a 36-in. diameter, 6-hearth, multi-hearth furnace, which is fired at about 1650°F. After passing through the carbon furnace, the carbon is quenched and moved by water eductors back to the carbon tower. The furnace has a throughput capacity of 75 lb/hr, thus requiring between 50 and 60 days to reactivate the contents of one carbon column.

From 1970 to 1974, there were 12 reactivation cycles at Colorado Springs. Number One tower was reactivated three times, Number Two tower five times, and Number Three tower four times. One of the carbon towers experienced considerably higher reactivation losses than the other two. No explanation is available as to why high losses would occur on carbon from the same batch, being split into three adsorbers, and receiving exactly the same on-line and reactivation conditions. If this adsorber is excluded, the average loss on reactivation losses do not include losses due to backwashing while on-line, but do include carbon losses from eduction and backwashing immediately after reactivation is completed. To determine carbon losses, the tower is first backwashed and drained before reactivation (the backwashing levels the carbon completely). A measurement is then taken of the carbon bed surface. After reactivation is completed and all reactivated carbon has been educted back to the adsorber, the tower is again backwashed to remove fines, drained, and measured. The difference in this bed depth is the "loss on reactivation."

When a carbon tower is exhausted, it is taken off-line and the carbon is moved by water eduction to a spent carbon holding tank. There are five, 4-in. pipe draw-off points in the floor of the tower, and all of the draw-off lines are connected to a main 4-in. header. This header connects to a 3-in. eduction line that transports the carbon to the spent carbon tank. Each draw-off line enters the tower and reaches different areas in the floor of the vessel. These lines may be opened individually or all at once depending upon the water pressure available to operate the eductor. It takes about 2 days to educt 94,000 pounds of carbon to the spent carbon tank.

When all of the carbon has been withdrawn from a tower, the reactivation begins. The carbon slurry is withdrawn from the spent carbon tank through a variable speed rotary displacement valve that measures the amount of carbon being fed to the furnace. This measured amount of carbon is moved by water eduction to an inclined dewatering screw. The screw includes a water seal baffle to prevent noxious odors from escaping the furnace and also to ensure positive pressure on the furnance. Spent carbon or carbon feed is sampled at this point in the process.

The dewatered carbon then enters the furnace at about 40 percent moisture. Temperatures of the six hearths may vary from one regeneration cycle to the next, depending upon the COD load contained on the carbon, the desired iodine number of apparent density, and the rate of carbon feed to the furnace. A typical temperature profile of the furnace hearths is: No. 1 (or top) - 700°F; No. 2 - 950°F; No. 3 - 1,250°F; No. 4 - 1,600°F; No. 5 - 1,550°F; and No. 6 - 1,650°F. The furnace has two burners each on No. 4 and No. 6 hearth only. Because the furnace has a throughput capacity of 75 lb/hr, it takes between 50 and 60 days to reactivate the contents of one carbon column. After reactivation, the carbon is quenched and moved by water eduction back to a tower. Virtually no plugging or erosion problems with this transportation system have been experienced.

Colorado Springs controls the carbon reactivation operation by the use of four simple laboratory analysis: iodine number, apparent density, sieve analysis, and the ash content. Results of a series of these tests are summarized in Table A-39. More complex analysis can be performed on activated carbon to determine various properties, but they are of little value in actually controlling the reactivation. Also, as the reactivation progresses, continual monitoring of all furnace functions is important. Significant controls are the temperatures of the various hearths, the carbon feed rate, and a positive pressure in the furnace. These controls are important in preventing "overburn" and high losses on reactivation.

TABLE A-39. ANALYSIS OF REGENERATED CARBON FROM ADSORBER NO. 2

Analysis/unit	Virgin carbon	Regenerated carbon average			
		Cycle 1	Cycle 2	Cycle 3	Cycle 4
Apparent dencity, g/cc	0.488	0.469	0.503	0.504	0.508
Iodine number	1040	886	824	802	785
Molasses decoloring index	7.6	8.3	8.5	8.1	-
Total ash, %	6.6	8.2	9.0	8.4	7.9
Effective size, mm	.97	-	1.02	1.06	1.07
Mean particle diameter, mm	1.58	1.80	1.63	1.66	1.68
Uniformity coefficient	1.71	-	1.62	1.62	1.59
No. 4 hearth temperature, °F	-	1586	1595	1593	1624
No. 6 hearth temberature, °F	-	1633	1575	1658	1634
Loss on regeneration, %	-	5.3	6.7	6.2	3.2

Carbon make-up at Colorado Springs has been 83,400 lb during 12 regeneration cycles, or 36.4 lb/mil gal treated. The total carbon dose (original fill plus make-up) is 160 lb/mil gal treated. These carbon losses include both reactivation and backwash losses. The reactivated carbon dosage only is 423 lb/mil gal of treated water. A total of 967,000 lb of carbon has been reactivated in the plant.

Operational Problems

Adsorption System--When backwashing a carbon adsorber there is always a chance of debris entering the backwash supply and plugging the backwash underdrain system. Tremendous pressures are developed and applied over very large areas during backwash. If the underdrainage system becomes partially plugged, backwashing pressure could be great enough to physically damage the vessel or piping. Precautions should be taken to prevent this damage from occurring by: (1) selecting the proper underdrain system; (2) insuring a clean, protected backwash supply; (3) installing pressure shut-off switches on backwash pumps to prevent over-pressuring underdrain system and piping; (4) installing pressure gauges above and below the underdrain system; (5) excluding air from backwash water. These gauges will measure the pressure differential being developed across the underdrain during backwashing. An automatic differential shut-down switch may be used or an alarm may be sounded.

Reactivation Furnace--Some findings and suggestions resulting from the experience at Colorado Springs regarding furnace operation are:

1. The installation of a fine screen basket in the overflow of the carbon dewatering screw proved to be a major step in preventing carbon losses. This screen is checked hourly by the operator to ensure that the screw speed is coordinated with the carbon feed rate from the rotary valve.

2. Carbon feed rate is critical in maintaining low loss in regeneration. If the furnace is overloaded, temperatures are difficult to maintain and the burners are called upon for more heat. The burner gas consumption and combustion air supply are increased and this condition results in critical stack gas velocities. These velocities can be great enough to entrain in the gas stream smaller carbon particles that are subsequently burned in the afterburner.

3. Visual inspection of the furnace scrubber water can be employed to predict high furnace efficiency or upsets in its operation; and

4. Positive pressure on the furnace should be maintained at all times.

The tertiary plant at Colorado Springs has been operating under severe loading conditions. For this reason, the results of plant operation are not too impressive from the standpoint of final effluent concentrations. When the high concentrations of pollutants in the influent to the system are considered, the tertiary process has been very satisfactory in removing gross amounts of contaminants. The tertiary process efficiency is strongly dependent upon the quality of secondary effluent being applied to it.

The carbon adsorption system does smooth out and remove some high concentration peaks, but to a limited extent; then effluent concentrations begin to be proportionally higher as the feed concentration increases. Figures A-39, A-40, and A-41 illustrate seasonal fluctuations in feed concentrations and the resulting effluent quality concentrations. The solids contact clarifier absorbs most of the fluctuations, but trends can definitely be seen in the carbon tower effluents. Table A-40 compares the tertiary water quality under the heavily loaded conditions of 1972 and after the start of the new activated sludge plant, which reduced the loading on the bio-filtration plant. Note that even though the carbon tower feed COD was reduced by 57 ppm or 50 percent, the final carbon effluent still showed only slightly improved reductions of 20 ppm or 39 percent. This information plus the curves illustrated in Figures 2, 3, and 4 indicates that the carbon system has limited capabilities in removal efficiencies under fluctuating feed concentrations. These data reveal that the carbon adsorption towers will only remove a given percentage of what is applied.

CAPITAL AND O&M COSTS

The unit cost of processed water at the Colorado Springs Tertiary Treatment Plant was $343/mil gal for industrial quality water during 1972. A comparison of these figures with the Advanced Water Treatment Plant at South Tahoe for the same year is made below.

	Capital Costs $/mil/gal	Operation & Maintenance $/mil gal	Total $
Colorado Springs	$76.01	$267.19	$343.20
South Tahoe	74.50	142.40	216.90

The capital costs compare quite closely, but there is an obvious difference in the respective operation and maintenance costs. The higher costs in the Colorado Springs plant probably are due primarily to undersized equipment in the calcining process, which results in constant overloading of the equipment and more frequent maintenance and repair. Another major factor in the unit cost discrepancy between the two plants is the cost of labor. The same number of operators are required to operate the 2 mgd facility at Colorado Springs as are needed to operate the 7.5 mgd Lake Tahoe plant. Also, the effluent quality of the bio-filtration plant may be a contributing factor in increased unit costs. Improvement in secondary treatment could conceivably result in a savings of approximately 5 to 15 percent in overall treatment costs.

As shown in Table A-40, costs were broken down into three categories: capital, operation, and maintenance. For simplification, the expenses for operation and maintenance were combined after being calculated. A further breakdown was made to determine the cost of individual systems in the tertiary plant. These individual systems were the tertiary headworks, chemical precipitation, lime calcining and feed, pH neutralization, filtration, carbon adsorption and regeneration, and processed water storage. Operation and maintenance costs are for 1972. The capital costs are at 1969 prices.

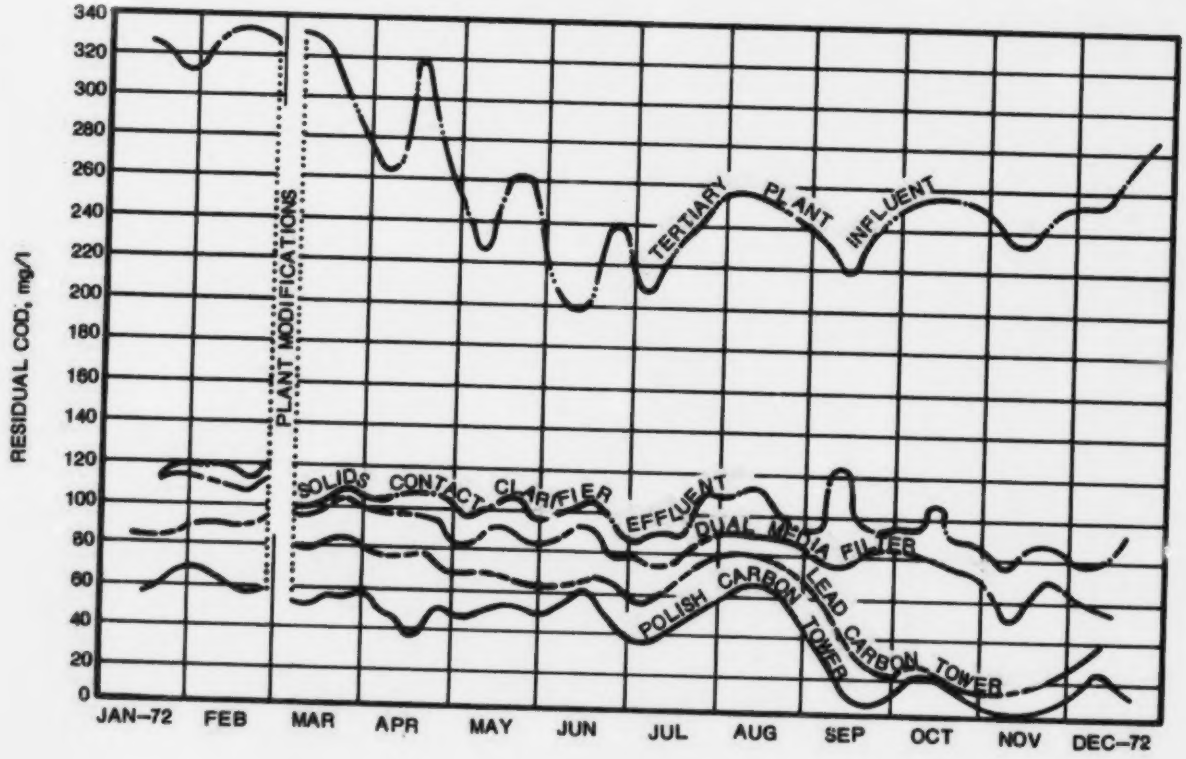

Figure A-39. COD concentrations in various unit process effluents.

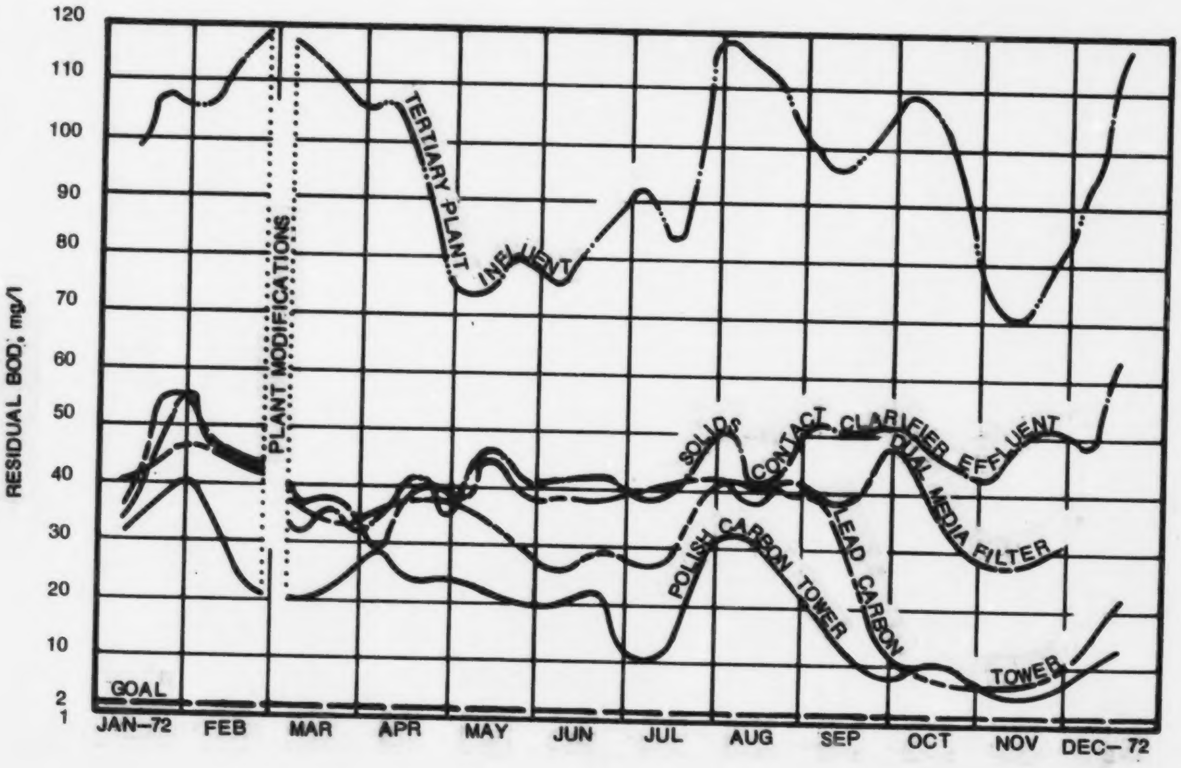

Figure A-40. BOD concentrations in various unit process effluents.

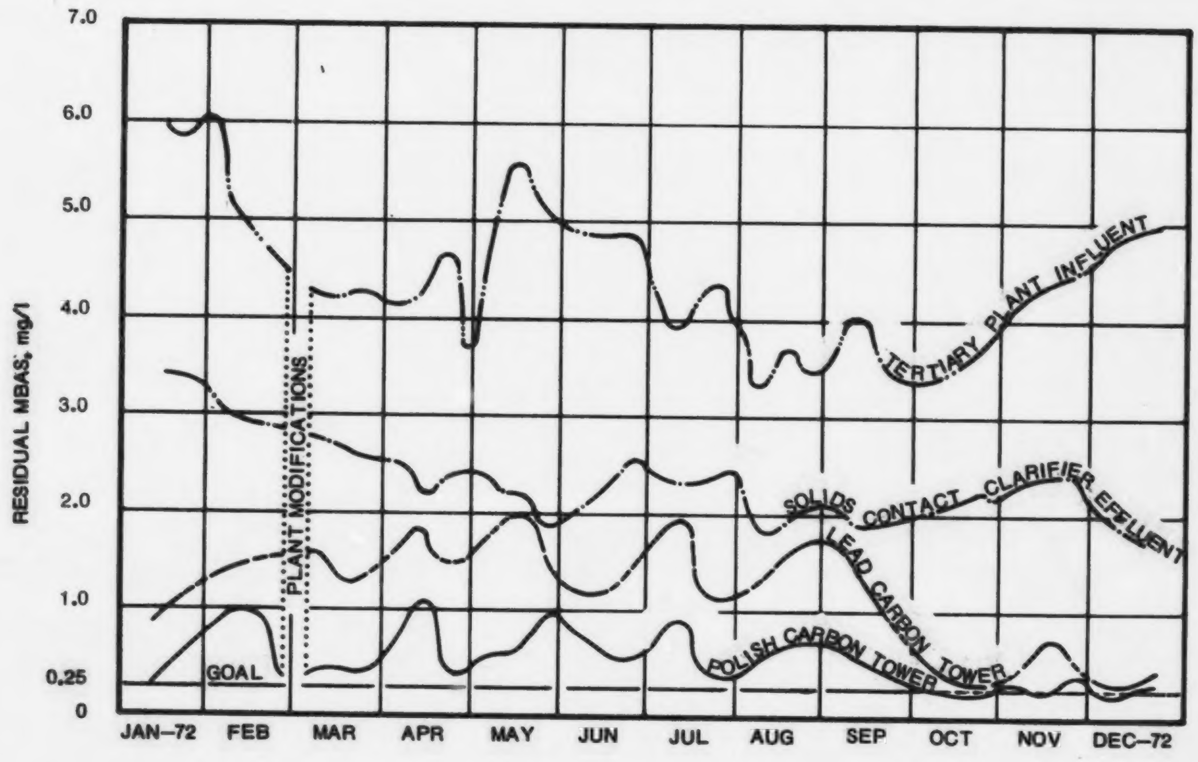

Figure A-41. MBAS concentrations in various unit process effluents.

TABLE A-40. GAC SYSTEM PERFORMANCE

	Heavy loading period - 1972			Light loading period*-1973-74		
Constituent†	Dual media effluent	Lead carbon effluent	Polish carbon effluent	Dual media effluent	Lead carbon effluent	Polish carbon effluent
BOD	46	29	21	27	21	13
COD	114	60	43	57	51	31
TOC	37	26	21	24	19	10
TSS	3.7	3.0	3.1	2.7	2.7	3.1
Turbidity	4.2	4.4	3.3	2.4	2.0	1.3
PO_4	1.7	1.5	1.4	1.3	1.5	1.4
MBAS	3.2	1.1	0.4	1.7	0.8	0.4
Color	38	22	11	17	15	7.4

*Operation after new activated sludge system went on-line.
†mg/L except color.

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A visit to the plant in August, 1979.

TABLE A-41. 1972 UNIT COSTS AT THE COLORADO SPRINGS TERTIARY TREATMENT PLANT

System	Plant flow, mg	Capital costs		Operation and maintenance		Totals	
		System cost, $	Unit cost, $/mg	System cost, $	Unit cost, $/mg	Total cost, $	Unit cost, $/mg
Headworks	602.30	1,793.00	2.98	1,936.00	3.21	3,729.00	6.19
Reactor clarifier	602.30	2,358.00	3.91	50,594.00	84.00	52,952.00	87.91
Lime calcining	602.30	14,050.00	23.32	15,324.00	25.44	29,374.00	48.76
pH neutralization	602.30	607.00	1.01	37,410.00	62.11	38,017.00	63.12
Carbon towers	506.80	10,159.00	20.05	16,766.00	33.08	26,925.00	53.13
Carbon regeneration	506.80	9,494.00	18.73	28,642.00	56.51	38,136.00	75.24
Dual media filtration	506.80	1,173.00	2.31	1,442.00	2.84	2,615.00	5.15
Reservoir	506.80	1,874.00	3.70			1,874.00	3.70
TOTALS		41,508.00	76.01	152,114.00	267.19	193,622.00	343.20

CASE HISTORY NO. 18
HERCULES, INC.
HATTIESBURG, MISSISSIPPI
INDUSTRIAL WASTEWATER TREATMENT

HISTORY AND INTRODUCTION

The Hattiesburg, Mississippi, plant of Hercules Incorporated produces a wide variety of industrial chemical typical of the naval stores industry including organic chemicals made from raw materials extracted from pine trees and stumps.

The plant contains 20 operating areas, each of which produces contaminated process wastewater. Process wastewaters are separated from sanitary wastes and noncontact cooling water and are discharged after treatment to a drainage ditch leading to the Bowie River. The Bowie River is a tributary of the Pascagoula River system. This river system has been the subject of several studies indicating that water quality problems, particularly low dissolved oxygen, exist at least part of the time. Although poor river water quality has not been directly attributed to the Hercules, Inc. discharge, Hercules along with the other major dischargers has initiated wastewater treatment practices to improve river water quality.

Although preliminary at-source treatment has been provided in most of the operating areas, treatment of the combined process wastes was required before the wastewater could be discharged. An impounding basin was constructed in 1951 to remove floating material (oils) and settleable solids from the combined process waste stream. Additional treatment was provided in 1972 when a dissolved air flotation (DAF) clarifier was installed. The impounding basin and DAF clarifier make up the primary wastewater treatment system. Table A-42 shows the TOC concentration and pH through the primary treatment process.

TABLE A-42. PRIMARY TREATMENT TOC AND pH

Stream	TOC, mg/L	pH
Untreated process waste	1200	3-4
Impounding basin effluent	400-500	3-4
DAF effluent	200-250	6-7

When it became necessary to provide additional treatment for removal of phenol and improved removal of TOC, a program to develop a secondary treatment system was initiated.

Two secondary treatment methods were considered to have potential application for use at Hercules, Inc.: biological treatment via the conventional activated sludge process and adsorption using GAC. Laboratory and pilot plant studies were conducted to determine the most efficient and cost effective method for treatment.

Results of activated carbon isotherm tests showed that 1 lb of COD could be adsorbed by each lb of carbon when treating the Hercules wastes. Pilot plant tests using GAC confirmed the isotherm results and showed that 45 min contact time, based on empty bed volume, would be required for 75 to 85 percent COD removal.

An activated sludge pilot plant was also operated on the Hercules waste to provide design data. This tretment method would provide treatment results comparable to the GAC adsorption process. Consruction costs for both processes were estimated in the same range. The adsorption process was chosen because of its minimal land requirements and its ability to continue to provide treatment in case of manufacturing process upsets.

The secondary treatment system, installed and started up in July, 1973, included mixed media filtration, GAC adsorption, and carbon reactivation.

DESIGN OF GAC SYSTEM

An upflow (countercurrent) adsorption system using packed columns of GAC was selected because of low estimated capital cost and anticipated efficiency of carbon use. Because of suspended solids in the primary treatment system effluent, filtration was required to prevent excessive headloss in the carbon adsorbers. A high-rate downflow filter was designed to filter the wastewater so that wastewater feed to the adsorption system would contain 5 mg/L or less suspended solids.

Table A-43 shows the performance criteria for the Hercules activated carbon adsorption system.

TABLE A-43. ADSORPTION SYSTEM PERFORMANCE CRITERIA

Parameter	Influent	Effluent
Flow		3.25 mgd
COD	700 mg/L	125 mg/L
TOC	200 mg/L	30 mg/L
BOD	250 mg/L	50 mg/L
Suspended solids		5 mg/L
Oil and grease		5 mg/L
pH		6-8

Basis of GAC Design and Operation

The purpose of GAC treatment at Hercules, Inc., is to remove organic materials including phenol from the process wastes. A schematic flow diagram for the GAC adsorption system is shown in Figure A-42. Partiallly treated waste from the primary treatment unit flows to a sump from which it is pumped to the mixed media filters and activated carbon columns. The activated carbon treatment system design basis is as follows:

Activated Carbon Treatment System

Flow rate	3.35 mgd
Number of carbon columns	Three in parallel
Type	Upflow, moving bed
Size of columns	12-ft diameter x 40-ft high
Granular carbon size	12 x 40 mesh
Carbon quantity (each column)	135,000 lb
Column flow rate (each)	780 gpm
Surface loading rate	6.6 gpm/ft^2
Contact time (empty bed)	48 min
Carbon exhaustion rate	6.3 lb/1000 gal (21,000 lb/day)

The totally closed carbon columns are made of 316 stainless steel and were designed with conical sections at the top and bottom. The vessels were designed for countercurrent operation with filtered wastewater entering the bottom and flowing upward to the top where the treated water exits the vessel via stainless steel conical screens. The treated effluent then flows to a treated water storage tank and discharges to the Bowie River.

As wastewater passes upward through the column, the activated carbon in the lower part of the column loses its ability to remove organics (becomes spent). Periodically, a small amount (or slug) of spent carbon is removed from the bottom of the column and an equal amount of fresh carbon is added at the top. In this way, the freshest carbon is in contact with the higher quality water to achieve the maximum removal of organic materials.

The spent carbon sludge removed from each carbon column flows to the slug measuring tank and then to the furnace feed tank. The slug measuring tank volume (5 percent of the volume of a carbon column) ensures that equal and exact volumes of spent carbon are transferred each time.

Spent carbon is moved from the furnance feed tank by a hydraulic eductor to a dewatering screw conveyor where the carbon is drained (dewatered) in preparation for thermal reactivation in a furnace. All carbon transfers are made in a water slurry.

In the reactivation system as originally designed and constucted, the dewatered carbon containing 50 percent moisture is discharged from the screw conveyor to the top hearth (Hearth No. 1) of a multiple hearth furnace. Rabble arms attached to a central rotating shaft move the carbon across the top hearth by means of rabble teeth (plows) toward the center of the furnace where it drops through a hole to Hearth No. 2. The rabbling process is repeated on each hearth moving the carbon outward and inward across successive hearths.

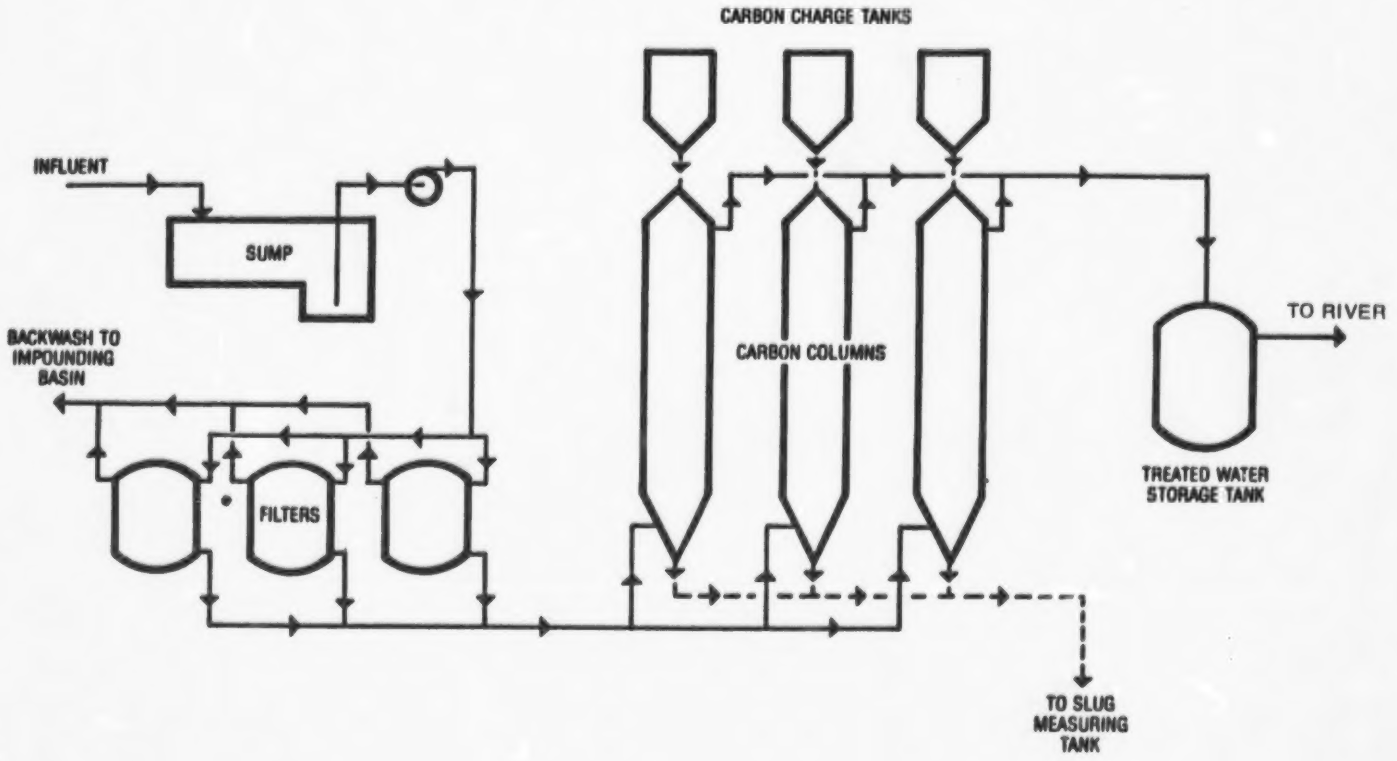
CARBON CHARGE TANKS
INFLUENT
SUMP
BACKWASH TO IMPOUNDING BASIN
FILTERS
CARBON COLUMNS
TO RIVER
TREATED WATER STORAGE TANK
TO SLUG MEASURING TANK

Figure A-42. Flow diagram of granular activated carbon adsorption system, Hercules, Inc.

The carbon reactivation system design basis is:

Granular Carbon Reactivation System

Furnace type	Multiple hearth
Furnace size	12'ft O.O. x five hearth
Furnace capacity	33,600 lb/day
Fuel	Natural gas/fuel oil
Afterburner, type	External
Carbon loss per cycle	5%
Makeup carbon	1050 lb/day

Moisture and some easily volatilized organics are driven off in the top hearths. As the carbon moves down through the furnace, the temperature increases and reaches a maximum at the lowest hearth (Hearth No. 5). Burners are located at Hearths 3 and 5 and temperatures range from 500° to 700°F at Hearth No. 1 to 1600° to 1800°F at Hearth No. 5. Steam is added on the fired hearths to improve reactivation.

As the hot reactivated carbon exits the furnace, it drops into a water filled quench tank where it is cooled and returned to a slurry form for transfer to the reactivated carbon storage tank. Reactivated carbon is transfered from storage to each of the three carbon columns by a pneumatically operated blowcase. A storage tank is also provided for virgin makeup carbon. Furnace off-gases (combustion products, moisture, and volatilized organics) are heated in a gas-fired afterburner located adjacent to the multiple-hearth furnace. Excess air is added to ensure complete combustion of volatile gases and odor. The hot gases then pass through a cooler and scrubber before being discharged to the atmosphere.

The reactivation and carbon handling system schematic diagram is shown in Figure A-43.

Operational Problems

Operation of the secondary treatment units was interrupted many times, particularly in the early operating years, by mechanical failure of many parts of the system. Failure of the mixed media filter discharge laterals caused the media to migrate to the carbon columns. This permitted high concentrations of suspended solids and oil and grease to enter the upflow packed activated carbon beds. High adsorber headloss resulted and carbon had to be removed and rectivated frequently in an effort to maintain effluent quality. When filter media mixed with spent activated carbon entered the reactivation furnace, the media melted and plugged portions of the furnace. The filter media also caused severe erosion of the carbon transfer system. On many occasions, the adsorbers experienced high headloss that could not be traced to unusually high suspended solids in the influent. The high headloss reduced the flow rate through the carbon, and effluent quality deteriorated. Odors became evident indicating septicity due to anaerobic biological activity within the carbon bed. As septic gases were generated, the headloss continued to increase. Headloss could be reduced and flow rate restored only by more frequent carbon column slugging and increased reactivation rate.

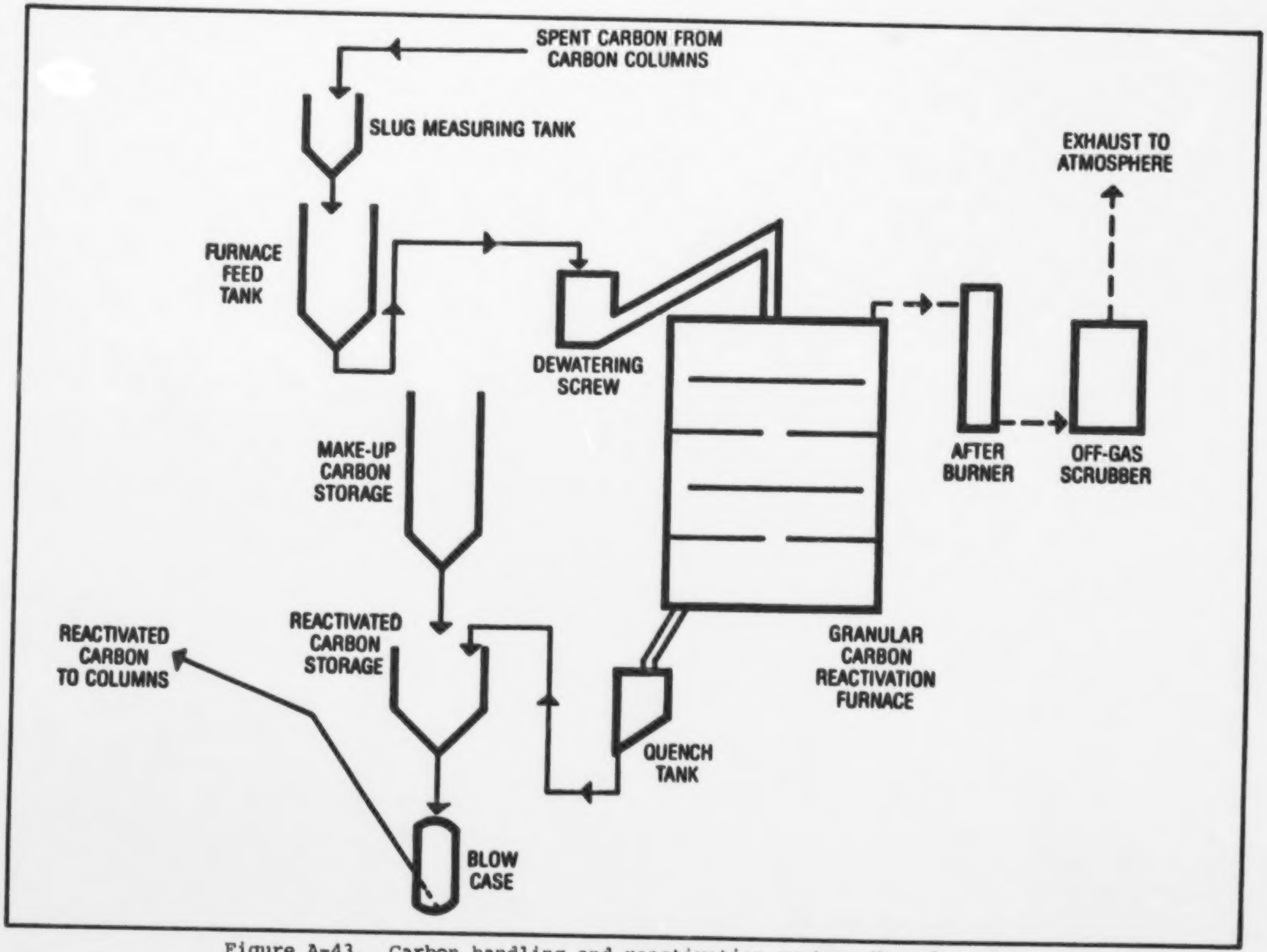
SPENT CARBON FROM CARBON COLUMNS
SLUG MEASURING TANK
FURNACE FEED TANK
DEWATERING SCREW
MAKE-UP CARBON STORAGE
REACTIVATED CARBON STORAGE
REACTIVATED CARBON TO COLUMNS
BLOW CASE
QUENCH TANK
GRANULAR CARBON REACTIVATION FURNACE
AFTER BURNER
OFF-GAS SCRUBBER
EXHAUST TO ATMOSPHERE

Figure A-43. Carbon handling and reactivation system, Hercules, Inc.

To improve operation of the GAC adsorption system and to control headloss, the packed bed adsorbers were modified in 1978 to permit operation in an expanded mode. The stainless steel vessels were extended at the top to permit expansion of the carbon bed and the outlet septa were removed to prevent binding by solids. With proper attention to flow rate through each adsorber to maintain expansion of the carbon bed, instances of high headloss have occurred less frequently.

The multiple hearth furnace has also been a factor in the operation of the adsorption system. The furnace was designed for 60 percent excess capacity to permit periodic high reactivation rates. Although the additional capacity was provided, the multiple hearth furnace experienced periodic mechanical failure requiring shutdown for repairs. Any furnace outage exceeding 48 hr resulted in poor performance of the GAC system because fresh carbon was not available for transfer to the adsorbers.

Major mechanical failures in the multiple hearth furnace have included failure of hearths, rabble arms, and center shaft. Each of these failures required repairs resulting in a minimum of 6 to 7 days downtime. During the first 4 years of operation, the furnace was inoperable 15 percent of the time and continued increasing each year.

Reactivation System Modification

In 1977 the multiple hearth furnace was replaced with a fluidized bed carbon reactivation furnace. This WESTVACO fluid bed reactivation furnace, which contains no unsupported brick work or high temperature moving parts, was installed and started up in 1978. As in a multiple hearth furnace, the wet spent carbon is dried at the top of the furnace at 300° to 500°F and is reactivated in the lower section at 1600° to 1800°F. Off-gases containing combustion products and water vapor pass through the afterburner, gas cooler, and scrubber, which are part of the original multiple hearth furnace system, before being discharged to the atmosphere. Although the afterburner can be fired if necessary for air pollution control, it has not been necessary to do so since the fluidized bed furnace began operation.

In Table A-44, the fuel and steam use in the Hercules multiple hearth furnace can be compared with that in a fluid bed activated carbon reactivation furnace at a typical carbon processing rate of 21,000 lb/day.

TABLE A-44. CARBON REACTIVATION FUEL AND STEAM CONSUMPTION

Furnace	Reactivation rate, lb/day	Fuel consumption, Btu/lb	Steam consumption, lb/lb	Steam consumption, Btu/lb	Total energy, Btu/lb
Fluid bed	21,000	2474	1.14	1323	3797
Multiple hearth	21,000	6000-7000	1.0	1161	7161-8161

Carbon losses in the fluidized bed furnace have ranged from 1.0 to 2.5 percent compared to the design estimate of 2.1 percent.

SYSTEM PERFORMANCE

The secondary wastewater treatment facility consisting of mixed media filtration and GAC adsorption at Hercules, Inc. plant at Hattiesburg, Mississippi, was started up in July, 1973. Due to in-plant modifications, the flow rate to the secondary treatment unit upon start-up was 2.6 mgd as compared to the design rate of 3.35 mgd. Dissolved organic quantities were, however, 35 percent greater than the design amount.

Results of wastewater treatment by GAC for removal of TOC are shown in Table A-45.

TABLE A-45. ACTIVATED CARBON PERFORMANCE, AVERAGE TOC REMOVAL*

	TOC			
Year	Influent, mg/L	Effluent, mg/L	Removed	Flow mgd
1973-75	300	116	61	3.2
1977	285	177	38	1.79
1978	281	189	33	1.66
1979 (Jan - June)	302	188	38	1.39

*The average effluent phenolics concentrations (calculated as phenol) for the years 1977, 1978, and 1979 (first six months) were 0.13, 0.13, and 0.14 mg/L respectively.

Exhaustion rates for the GAC averaged 9.5 lb/1000 gal wastewater treated. Carbon loadings have ranged from 0.1 to 0.44 lb TOC/lb carbon, and losses have average 8 percent during periods of typical operation. Typical carbon losses attributed to the reactivation furnace have been 5 percent.

CAPITAL AND OPERATION AND MAINTENANCE COSTS

Capital Cost

The capital cost for the GAC adsorption and reactivation systems was $1,422,000 in 1973. That included the cost of vessels, piping, reactivation furnace, controls and instrumentation, and initial fill of GAC. In 1979, the three stainless steel carbon columns were extended at a cost of $200,000.

Operating and Maintenance Cost

The annual costs of operating the Hercules secondary wastewater treatment facility are presented in Table A-46.

TABLE A-46. AVERAGE MONTHLY OPERATING COST

Item	1973-75 Avg.	1977	1978	1979
Operation	$ 4,831	$12,258	$19,208	$18,046
Maintenance	7,619	8,167	13,617	16,737
Utilities	4,828	8,000	9,258	10,117
Carbon	12,908	23,825	22,375	26,679
Total	$30,186	$52,250	$64,458	$71,579

During the first 2 years of operation, the average monthly use of activated carbon was 33,273 lb. Total cost of carbon treatment was $0.314/1000 gal.

As the cost of operation and maintenance has risen, the amount of wastewater requiring treatment has been reduced. Operating costs based on the quantity of wastewater treated each year are:

Year	$/1000 gal
1973-75	0.314
1977	0.97
1978	1.29
1979	1.47

None of the operating cost figures reflect or include amortization of capital.

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CASE HISTORY NO. 19
INDUSTRIAL SUGAR, INC.
ST. LOUIS, MISSOURI
SUGAR REFINERY

HISTORY AND INTRODUCTION

The Industrial Sugar, Inc., sugar refinery at St. Louis, Missouri, manufactures high purity liquid cane sugar for use in the soft drink industry and in other industries that use liquid sugar. Raw granular cane sugar purchased from cane sugar mills is used as the raw material. Before refining, the liquid sugar normally contains 800 color units and is a dark amber color. The sugar may, however, contain as high as 3200 color units depending on the source of the raw granular sugar. The final product is a high purity water clean solution containing 77 percent solids (77 Brix).

Sugar refining operations at Industrial Sugar, Inc., began in 1958 with the use of GAC for decoloring the liquid sugar. In 1965, a multiple hearth furnace was installed to reactivate the granular carbon for reuse.

DESIGN OF GAC SYSTEM

Raw granular sugar is first placed in solution by addition of water and steam. Refining steps include filtration for removal of particulate impurities, adsorption by GAC for color removal, and ion exchange for removal of inorganic impurities.

The original activated carbon adsorption system at Industrial Sugar, Inc., included six downflow columns each 9 ft in diameter and 9 ft high, containing nearly 600 ft^3 of 12 x 40 mesh coal based carbon. The columns were operated in two parallel "trains" of three each in series. Piping was arranged so that any of the columns in each train could be operated in any position from lead to final polishing.

The refinery was later expanded by adding four 10-ft diameter downflow columns each containing 1200 ft^3 of carbon. The larger vessels are operated in series and also in series with the smaller columns. Figure A-44 presents a schematic flow diagram of the adsorption system.

All of the columns are made of carbon steel and are lined with an abrasion resistant food grade epoxy lining to prevent corrosion. Stainless steel screens (Nevaclog) are mounted in the columns to support the carbon beds. The original columns were built with standard dished heads and the screens were installed horizontally. Carbon is removed through a pipe nozzle located in the vertical column side immediately above the screen. The more recently installed columns have slightly conical bottoms, and carbon is discharged through an opening in the center of the cone.

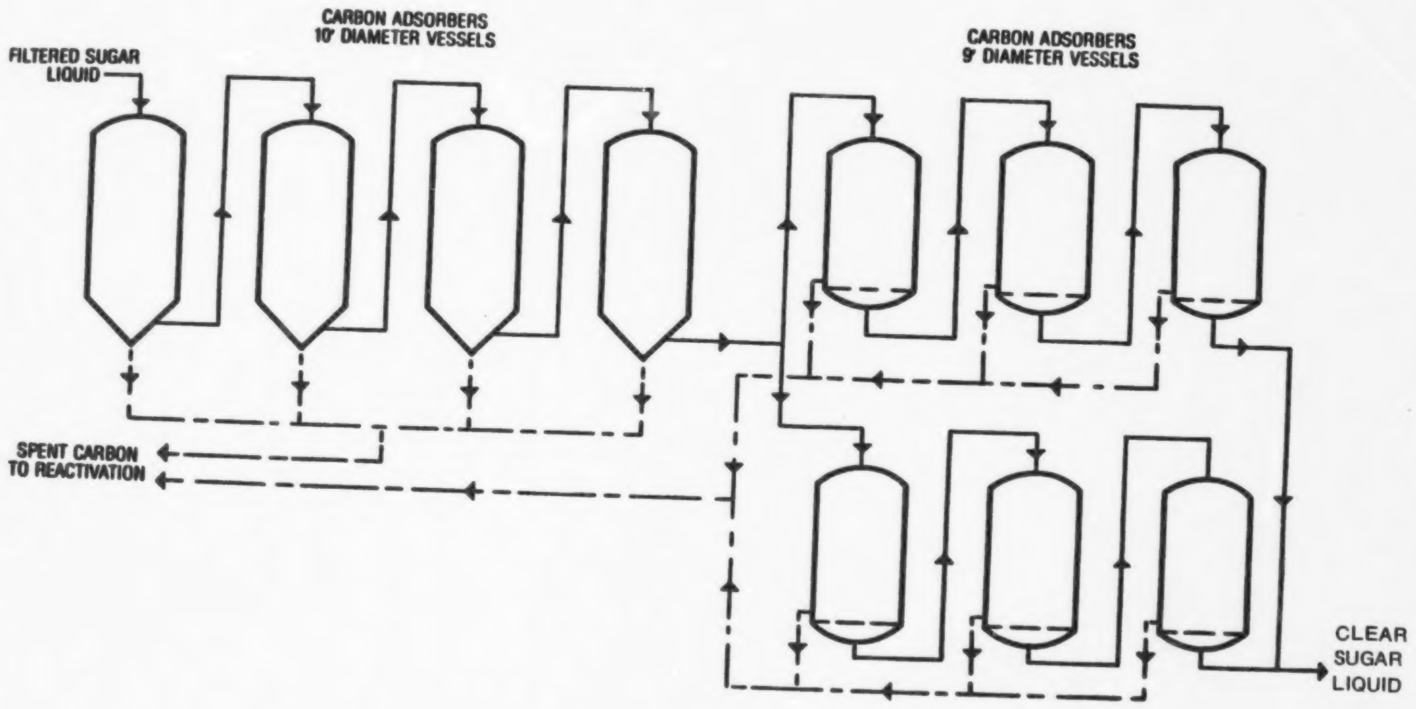
CARBON ADSORBERS
10' DIAMETER VESSELS
CARBON ADSORBERS
9' DIAMETER VESSELS
FILTERED SUGAR LIQUID
SPENT CARBON TO REACTIVATION
CLEAR SUGAR LIQUID

Figure A-44. Schematic flow diagram of granular activated carbon adsorption system, Industrial Sugar, Inc.

All carbon transfers from the columns are made by pressurizing the vessel and blowing the carbon out in a water slurry. A small heel of carbon is left in the column each time carbon is removed, but its effect on the operation has not been considered significant.

The carbon columns are designed for downflow operation with the sugar solution entering the top of the column and exiting from the bottom. It then flows to the top of the next column in series and continues in that manner through the adsorption system.

As color molecules are adsorbed on the GAC, the ability of the carbon to continue to remove color becomes limited and the carbon becomes exhausted or spent in relation to the material being adsorbed. When the carbon in the lead column in the series becomes spent or approaches a spent condition, it is removed from service for reactivation. At that time, the second column in the series becomes the lead column.

When the column is taken out of service, the spent carbon is "sweetened off" by rinsing with clear water to recover as much sugar as possible before reactivation.

When GAC becomes spent, the activity can be restored thermally in a reactivation furnace for reuse. Industrial Sugar, Inc., uses a multiple hearth furnace for reactivation. After a column is taken out of service and "sweetening off" is complete, the carbon is transferred in a water slurry to a spent carbon storage tank where it is dewatered by allowing the water to drain down through a screen. The dewatered carbon containing 39 to 40 percent moisture is transferred by a screw conveyor to the top of the reactivation furnace. The design bases for the adsorption and reactivated systems are:

Adsorption System

Number of adsorbers	Six, 9-ft diam Four, 10-ft diam
Mode of operation	Downflow, series
Depth of carbon (total)	90 ft
Contact time	18 hr
Type and size of carbon	Granular, 12 x 40 mesh

Reactivation System

Furnace type	Multiple hearth
Furnace size	6-ft O.D. x six hearth
Furnace capacity (design)	10,000 lb/day
Fuel	Natural gas

The dewatered spent carbon enters at the top of the multiple hearth furnace where it is dried first at about 400°F. As it passes downward through the furnace, the temperature increases to a maximum of 1600°F at the bottom hearth (Hearth No. 6). Two burners, one located on Hearth No. 4 and one on Hearth

No. 6, provide the necessary heat for reactivation. Steam may also be added at the fired hearths if desired.

Reactivation off-gases, drawn off the top of the furnace and through a cyclone separator by an induced draft fan, are then discharged to the atmosphere. Any particulates removed by the cyclone are returned to the furnace.

After the carbon is reactivated, it drops from the furnace into a water-filled tank for cooling and a rubber lined centrifugal pump pumps it to a reactivated carbon storage tank. When sufficient reactivated carbon is available, it is transferred by an eductor in a water slurry to the empty column. That column then becomes the final or polishing column in its series.

A schematic flow diagram of the carbon handling and reactivation system is shown in Figure A-45.

SYSTEM OPERATION AND PERFORMANCE

Since startup of the multiple hearth reactivation furnace in 1965, the adsorption and reactivation systems have operated with a minimum of operator attention. The adsorption system operates at a constant flow, which provides 18 hr of contact time. Whenever the flow of filtered liquid sugar to the adsorption system is interrupted or the desired flow rate cannot be maintained, the adsorbers are automatically placed in a recycle mode so that all of the flow is recycled within the adsorption system. Similarly, if downstream processes demand less decolorized liquid sugar, the refinery operator can initiate recycle.

The reactivation rate of spent carbon--normally 2 lb carbon/hundred weight of raw sugar--is controlled by the reactivation furnace capacity. Activated carbon in an adsorber that is the most heavily loaded with organic color is transferred to the reactivation system as soon as a dewatering tank is available. Because of this method of operation, none of the carbon becomes completely exhausted with respect to the influent color concentration.

The reactivation furnace, designed for a nominal reactivation capacity of 10,000 lb/day is operated at a rate of 12,000 lb/day. The spent carbon is dewatered as completely as possible in a dewatering tank and is conveyed to the furnace at a minimum moisture concentration (usually 39 percent). Furnace operating temperatures at the bottom reactivation hearths are closely maintained at 1600°F. Although steam can be added at the fired hearths, no improvement in reactivation efficiency or reactivated carbon quality has been noted at Industrial Sugar, Inc. with its use, so it is not currently used in the reactivation process. By operating the furnace at a constant rate and temperature, all of the reactivated carbon in the system is of a consistent quality.

Apparent density of the GAC is the parameter used for controlling and evaluating the reactivation process. Samples of reactivated carbon are collected every 30 min and a composite sample of spent carbon is collected over

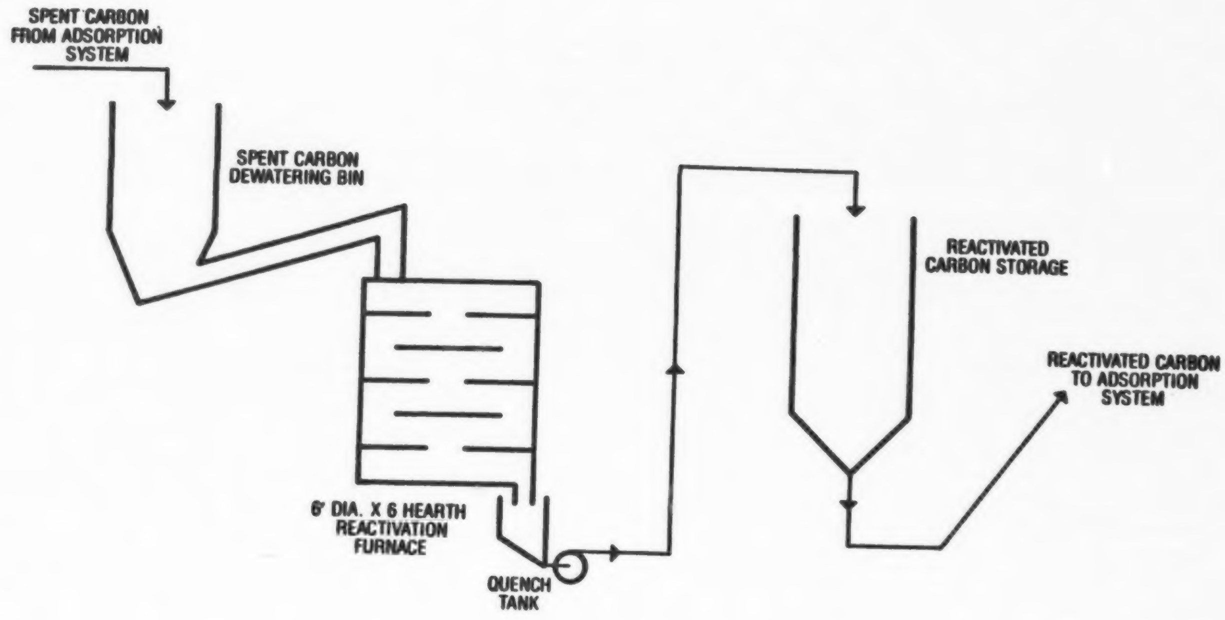
SPENT CARBON
FROM ADSORPTION
SYSTEM
SPENT CARBON
DEWATERING BIN
6' DIA. X 6 HEARTH
REACTIVATION
FURNACE
QUENCH
TANK
REACTIVATED
CARBON STORAGE
REACTIVATED CARBON
TO ADSORPTION
SYSTEM

Figure A-45. Schematic flow diagram of carbon handling and reactivation system, Industrial Sugar, Inc.

a 24-hr period for the apparent density test. Reactivated carbon apparent density is always 5 g/100 cc less than that of the spent carbon as shown by the following typical values.

Spent carbon	Reactivated carbon	Makeup carbon
59-60 g/100 cc	54-55 g/cc	49-50 g/cc

The furnace off-gas system consisting of an induced draft fan and cyclone separator has never experienced any air quality violations.

The major repair item has been relining the reactivation furnace; this has been done twice. The last relining occurred in 1978 for an average lining life of 6.5 yr.

Although the furnace is shut down for 48 hr every weekend, there have been no serious refractory or hearth failures. Because of the size of the furnace and its construction, the hearths must be removed and replaced with each relining.

CAPITAL AND OPERATION AND MAINTENANCE

Capital Cost

The reactivation system, as originally installed, included dewatering bins, furnace feed screw conveyors, multiple hearth furnace, quench tank, and carbon transfer pump. The total capital cost of the reactivation system, installed in 1965, was $125,000.

Operation Cost

No record of costs associated with operating the adsorption or reactivation system has been maintained. Although the furnace uses natural gas for fuel, the fuel use for reactivation is not known because it is not metered separately. Industrial Sugar, Inc., plans to install a gas meter for the furnace because of rising fuel prices.

Carbon losses are not monitored on a short-term basis but have been calculated to be 2.5 percent based on annual purchases of GAC for make-up.

The annual cost of maintenance and repair of the activated carbon adsorption and reactivation systems have not been documented but are considered minimal.

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CASE HISTORY NO. 20
AMERICAN WATER WORKS SERVICE COMPANY
HOPEWELL, VIRGINIA
MUNICIPAL WATER PURIFICATION

HISTORY AND INTRODUCTION

The American Water Works Service (AWWS) Company is the largest investor-owned water utility in the United States, currently supplying about 5 million people through 100 systems in 20 states from coast to coast. Their experience with GAC began in 1960 at Hopewell, Virginia, where they installed GAC to remove taste and odor. This was the first such installation of this kind in this country at a drinking water plant. By 1975, 46 U.S. plants had partially or completely converted to GAC. Only six used GAC after conventional filtration. About one-third of these 46 plants are part of the AWWS system. Since 1975, many more plants have come to use GAC. AWWS Company recently completed its largest installation at Chattanooga, Tennessee, (72 mgd) which makes 19 locations within the Company at the present time. Table A-47 shows the current list. Hopewell, interestingly, is the only plant that uses GAC as a post contactor; the GAC can be expected to remove the earthy odor caused by geosmin for a period of only 30 to 60 days.

TABLE A-47. AMERICAN WATER WORKS SYSTEM LOCATIONS PRESENTLY USING GAC

	Bed depth, in	Gac, lb	Capacity, mgd
Illinois			
E. St. Louis	18	412,200	35
Granite City	18	174,000	13
Peoria	30	165,000	30
Indiana			
Kokomo	20	162,000	11
Muncie	24	90,500	8
Richmond	24	100,900	8
Terre Haute	30	127,000	6
Iowa			
Davenport	24	331,700	30
Kentucky			
Lexington	14	177,600	20
Ohio			
Ashtabula	24	75,000	4
Marion	18	80,000	7

TABLE A-47. Continued

	Bed depth, in	Gac, lb	Capacity, mgd
Pennsylvania			
New Castle	30	190,800	8
Pittsburgh	30	1,947,400	86
Tennessee			
Chattanooga	30	927,400	72
Virginia			
Hopewell	60	81,000	3
West Virginia			
Huntington	30	337,500	24
Madison	18	7,300	1
Princeton	18	24,300	3
Weston	18	14,600	1
Total 19	—	5,426,200	370

GAC SYSTEM

Figure A-46 shows the Hopewell plant flow diagram. The Appomattox River, source of supply for Hopewell, receives back water from the nutrient-rich James River during high tide, thereby providing ideal conditions for growth of actinomycetes. Because the James River water quality has improved over the years, a 1-year service life is now obtained from the GAC.

Regeneration capability was not installed at Hopewell. After the first few exchanges of GAC, some filter sand was replaced with partially spent GAC, to get a longer contact time. The carbon could still dechlorinate after it was exhausted for taste and odor control. Since the plant had been dechlorinating with sodium bisulfite, enough sand filters were converted to spent carbon filters to accomplish the same degree of dechlorination. When carbon was tested in parallel with sand for suspended solids removal, the carbon did slightly better than sand without affecting its dechlorinating properties (See Table A-48). After 10 years, some carbon was still dechlorinating. Since then, many others have verified GAC's ability to remove suspended matter, and it is now fully accepted as a filter medium.

Over the years, it was found that the iodine number (an indication of available surface area) of GAC decreases with use, which means that the carbon pores are becoming filled with organic compounds. When the iodine number gets down to around 300 (virgin material ranges from 650 to 1100), the carbon is no longer effective enough to ensure taste and odor control. While the iodine number drops, the apparent density (the weight of carbon per unit volume) increases, also indicating pickup of organic chemicals. An increase of about 20

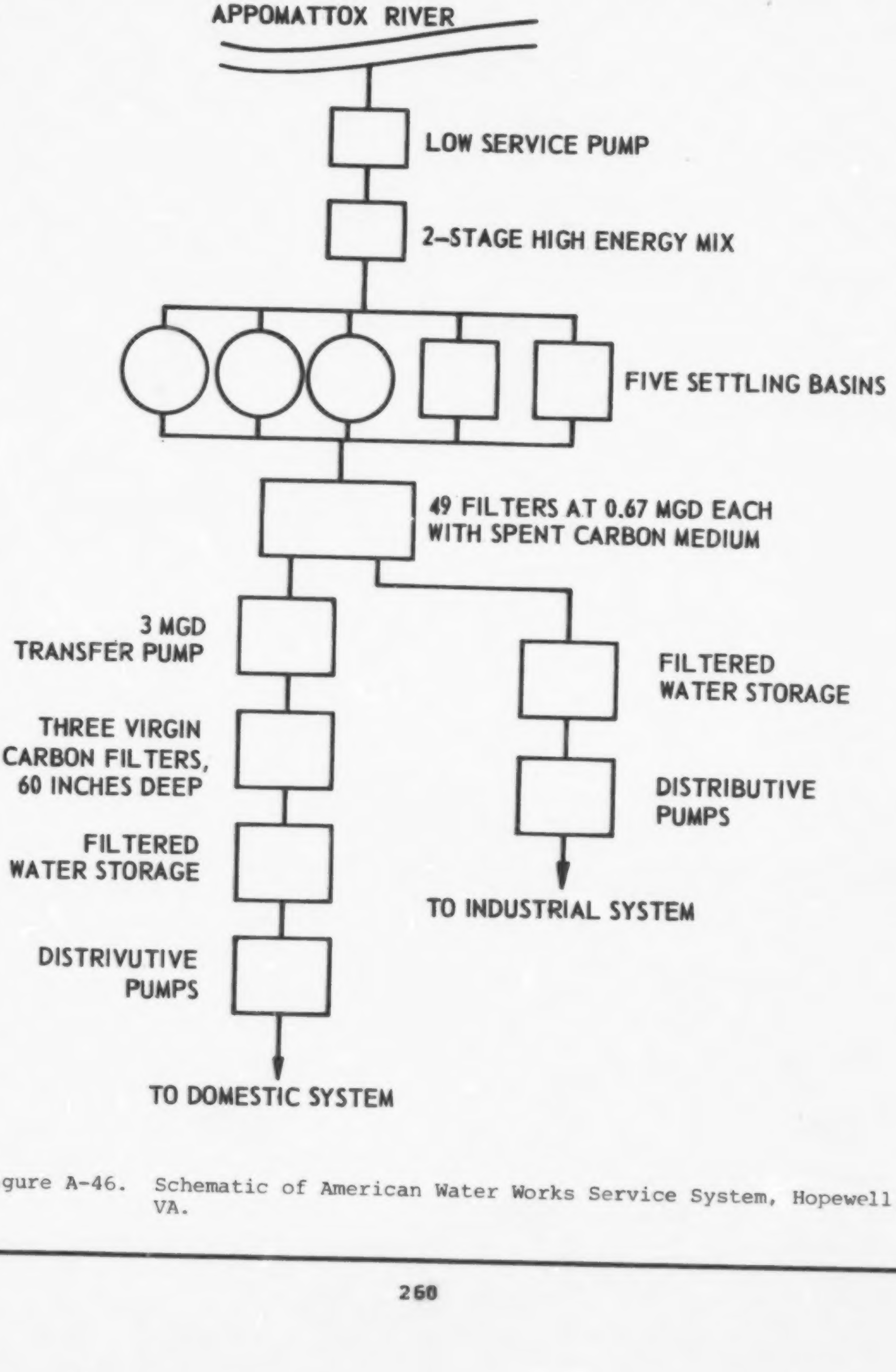
APPOMATTOX RIVER
LOW SERVICE PUMP
2-STAGE HIGH ENERGY MIX
FIVE SETTLING BASINS
49 FILTERS AT 0.67 MGD EACH
WITH SPENT CARBON MEDIUM
3 MGD
TRANSFER PUMP
THREE VIRGIN
CARBON FILTERS,
60 INCHES DEEP
FILTERED
WATER STORAGE
DISTRIVUTIVE
PUMPS
TO DOMESTIC SYSTEM
FILTERED
WATER STORAGE
DISTRIBUTIVE
PUMPS
TO INDUSTRIAL SYSTEM

Figure A-46. Schematic of American Water Works Service System, Hopewell, VA.

TABLE A-48. IMPURITY REMOVAL BY ADSORPTION - FILTRATION CARBON BEDS[*] AND BY SAND MEDIUM

Impurity	Influent	Carbon bed Effluent	Sand medium Effluent
Threshold odor number	35-140	0-4	35-70
Color	4-14	0-2	1-2
Manganese, ppm	0.066-0.15	0.008-0.017	0.008-0.017
Iron, ppm	0.2-0.37	0.006-0.025	0.012-0.087
Turbidity	0.45-1.4	0.07-0.15	0.10-0.25
Chlorine, ppm	1.4-2.8	0-0.25	1.4-2.8

[*] 24-in. deep at 2 gpm/ft^2.

[†] Extracted from: "Removal of Organic Contaminants by Granular Carbon Filtration" by Hager and Flentje, JAWWA, November, 1965.

[§] Odor samples over 60 day period; other data 150 day period.

percent (0.52 to 0.60 gm/cm^3) seems to accompany the drop in the iodine number. Figures A-47 and A-48 show these effects. A threshold odor number of 3 seems to corrolate with the Iodine number and the apparent density as described above; knowing this, they can be used as operating parameters.

SYSTEM OPERATION AND PERFORMANCE

Although the AWWS Co. installed GAC only in plants where severe taste or odor problems had been experienced, it was recognized that other organics were being removed, and the extent of such removals was investigated.

Work done by EPA and others concerning the adsorptive capacity of GAC for trihalomethanes and other organics has indicated the life of the GAC is short. At Hopewell, data indicated a 78 percent THM removal after 9 months of operation and the processing of 0.23 mil gal of filtered water/ft^3 GAC (see Table A-49). Therefore, it appears that the bed life for trihalomethane removal can possibly be greater than has been previously reported, but cannot be accurately predicted without specific evaluation on a case-by-case basis.

Although the GAC has been installed in AWWS Company plants basically for taste and odor removal, there are indications that specific organic removal does occur over a long period of time. This was indicated at the Hopewell, Virignia, plant in the removal of kepone: the average kepone in ppb, in the river water was 0.017; before GAC, 0.011; and after GAC, 0.001. These data were developed from an average of 60 samples over a 2-yr period.

Handling GAC

During the past 20 years, AWWS Company has handled millions of pounds of carbon. They have used hand shovels, pails, drums, eductors, eductors on hoists with trolleys, cranes with buckets, and vacuum trucks--all of which work.

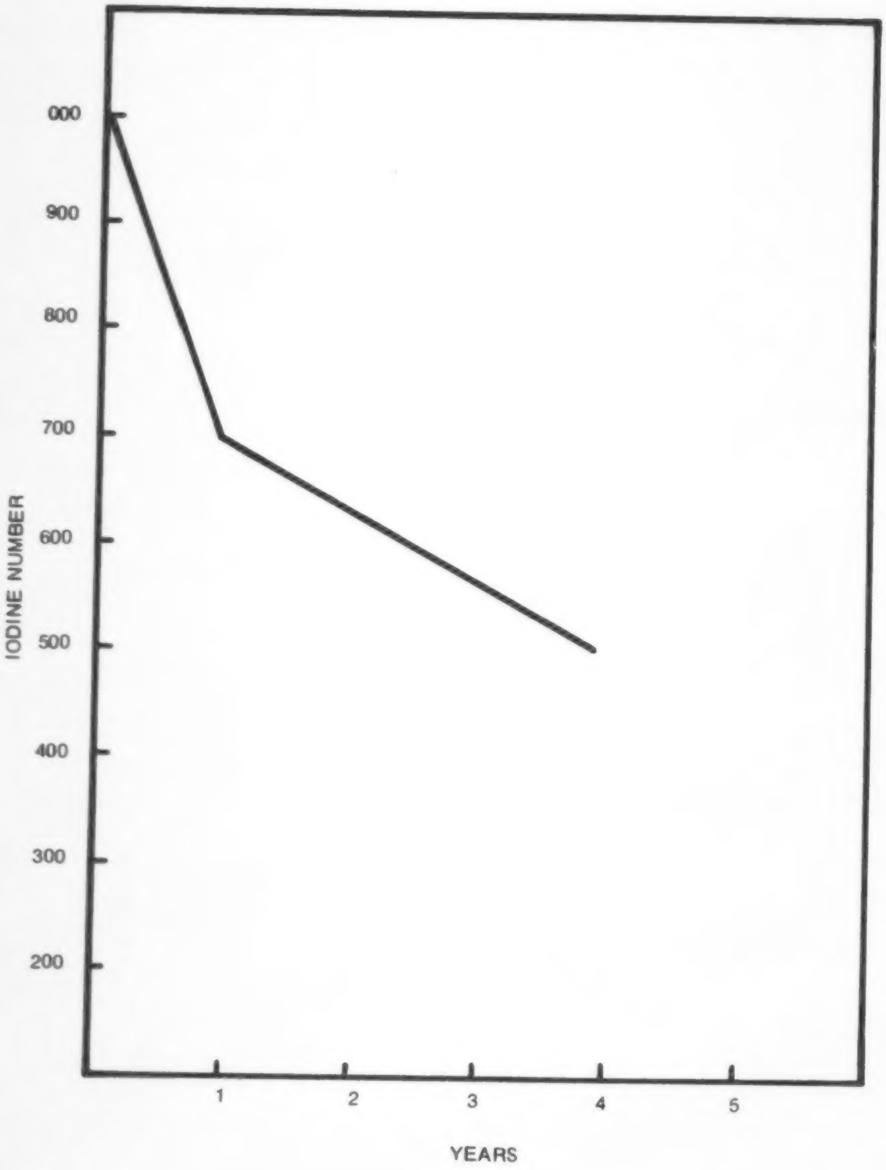

Figure A-47. Typical iodine number vs. time relationship.

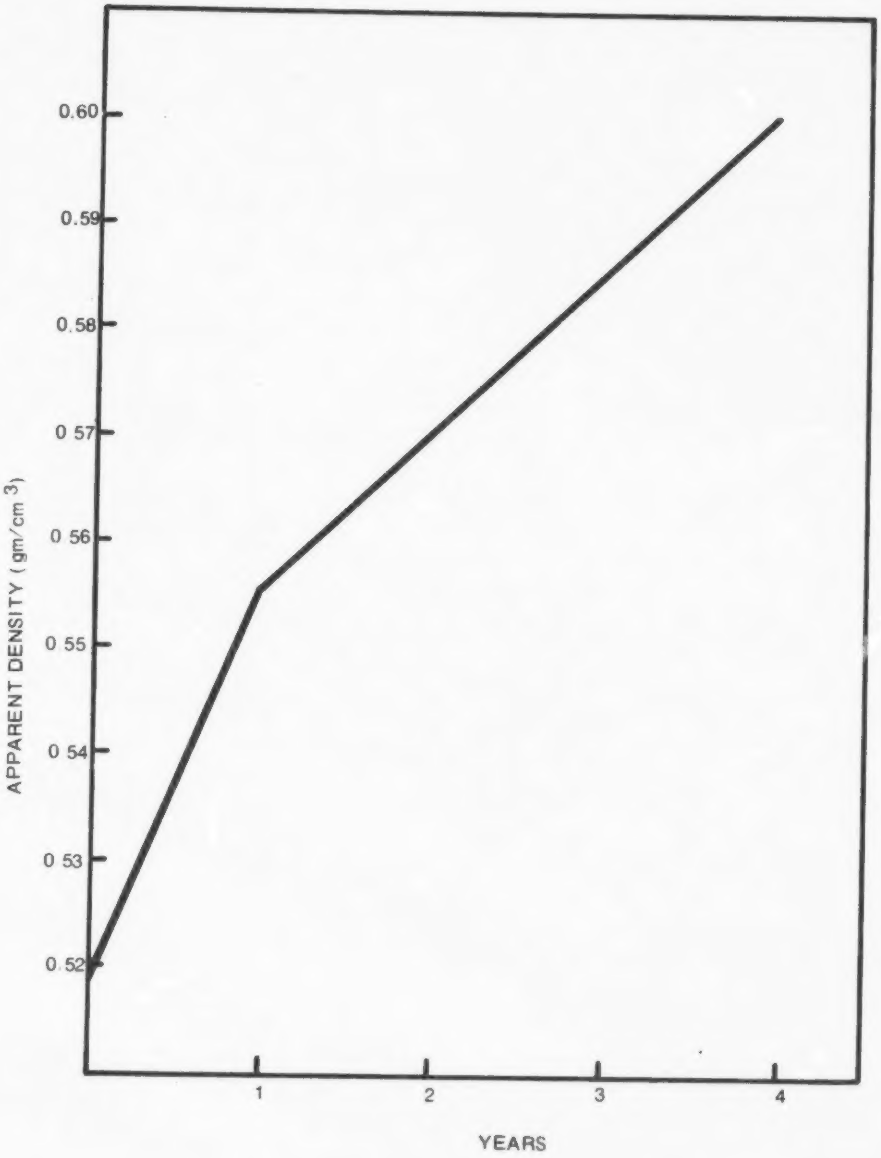

Figure A-48. Typical apparent density vs. time relationship.

TABLE A-49. TRIHALOMETHANES AT HOPEWELL, VA PLANT EFFLUENT

	7-mo old GAC		9-mo old GAC	
	Pre GAC	Post GAC	Pre-Gac	Post-GAC
Chloroform	77	55	261	68
Dibromochloromethane	22	5	1.9	3.3
Dichlorobromomethane	17	<1	191	27
Bromoform	20	2	<1	<1
TTHM (ppb)	136	62	454	98
% Removal TTHM	54%		78%	

Undoubtedly, the Hopewell plant personnel have the most experience. To remove GAC from the filters, the water eductor is used in combination with a periodic backwash at low rate. By maneuvering the suction hose around the filter, virtually all the carbon can be removed, even where gravel is supporting the carbon. When sand is present, it is more difficult to remove all the carbon without getting sand mixed with it. But the system works very well, and with a little equipment and a little experience, 800 cf can be removed from a 1 mgd filter in less than 4 manhours.

Problems With GAC Use

Most of the AWWS Company experience has been with GAC from bituminous material, but lately they have had good success with lignite. There were some problems with its use. Since GAC is lighter than other media, backwash rates had to be lowered to prevent loss of material. In addition, the rate as a function of water temperature and particle size suddenly became a crucial operating parameter. Figure A-49 shows this relationship. Many times, more precise wash flow control had to be installed to prevent loss of the relatively expensive material. Recently, it was found that some carbons require higher wash rates, which may demonstrate a change in carbon raw materials or in processing. Nevertheless, with variation like this, filter washing of GAC requires closer operational control than does any other medium. Even with good control, some carbon gets washed away--perhaps 2-in./yr.

Another problem is the possible accumulation of mud in the media. This does not happen in all cases, but when floc particles are particularly cohesive, as in a highly polymer-dosed water, the floc does not wash away readily at these low wash rates, even when wash times have been extended. Wash water consumption does not always decrease with use of GAC (because of lower rates); in actuality, wash water consumption may increase due to the extended times required to clean the bed.

Because of the dechlorination capacity of GAC, bacteria may multiply in carbon beds; the filtered water may contain bacteria many-fold higher than the inlet water. Total plate count bacteria have been controlled to some extent by backwashing with chlorine up to 50 ppm of combined residual. Fortunately, post chlorination usually lowers the total plate count to less than 10 colonies/mL.

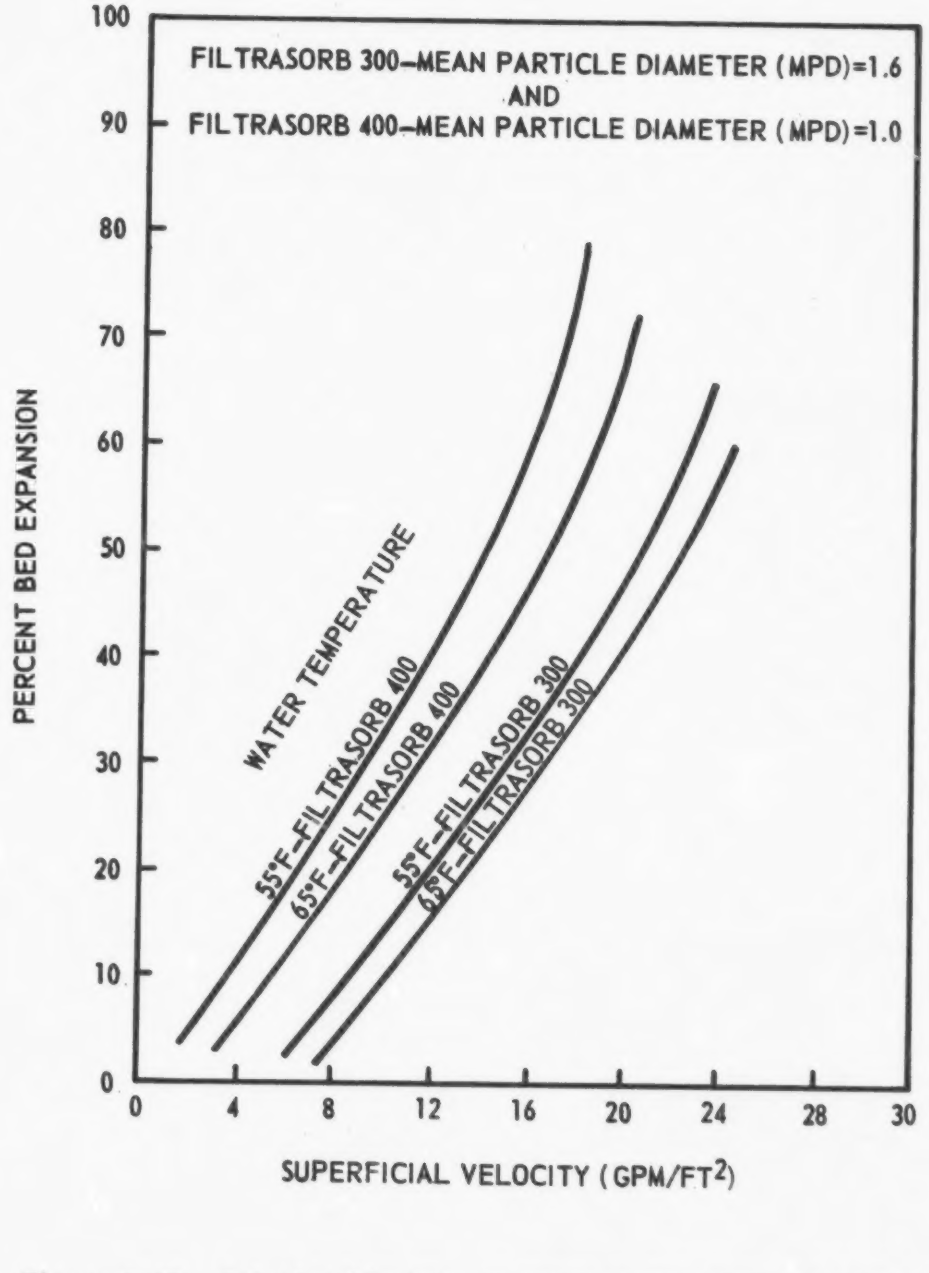

Figure A-49. Relationship between water temperature and particle size of GAC during backwashing.

CAPITAL AND OPERATION AND MAINTENANCE COSTS

Despite some problems, GAC is an excellent operating tool at a cost which is not exorbitant, for taste and odor control. Table A-50 gives some recent cost data, exclusive of capital cost of installation, for GAC operation after several years operation. These costs do not reflect the decrease in other taste and odor chemicals, any change in wash water, any change in chlorine consumption, or any savings in sludge disposal. The overall cost reudction for just taste and odor control at these locations has been 34 percent.

The AWWS Company plans and budget for calendar year 1980 at Hopewell are to treat the anticipated flow of 1,460 mil gal with 85,000 lb of virgin carbon at a cost of $41,140. The GAC cost is 48.4¢/lb, and the cost per 1000 gal of water treated is 3 cents. The virgin carbon will be placed in the three final filters for taste and odor control. The spent carbon from these filters will be transferred to other beds for dechlorination service. In the process, some incidental benefit will be derived in the form of trace organics removal.

TABLE A-50. COST DATA FOR AWWS COMPANY PLANTS - OPERATION ONLY

Plant	Capacity mgd	Raw water source	$/mil gal
Ashtabula, OH	4	Lake Erie	3.70
Chattanooga, TN	81	Tennessee River	5.73
Davenport, IA	30	Mississippi River	16.30
E. St. Louis, IL	35	Mississippi River	3.38
Granite City, IL	13	Mississippi River	8.35
Kokomo, IN	11	Wildcat Creek	4.63
Lexington, KY	20	Private Reservoir	3.95
Marion, OH	7	Wells and Scioto River	3.71
Muncie, IN	8	White River	6.57
Peoria, IL	30	Illinois River	11.68
Richmond, IN	8	Private Reservoir	6.19
Terre Haute, IN	6	Wells and Wabash River	3.47
Total	253		6.47 avg

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Moser, R. H. and Blanck, C. A., "Experience with Granualr Activated Carbon for Taste and Odor Removal", proceedings of AWWA Seminar on Controlling Organics in Drinking Water, June, 1979.

Plant visit; information provided by Morton Simon and Clarence Blanck of AWWS Company.

CASE HISTORY NO. 21
AMERICAN WATER WORKS SERVICE COMPANY
DAVENPORT, IOWA
MUNICIPAL WATER PURIFICATION

HISTORY AND INTRODUCTION

The 106-yr-old Davenport filter plant treats an average of 18 to 20 mgd (a maximum of 30 mgd) and uses a treatment sequence that includes prechlorination, coagulation with aluminum sulfate and cationic polymer, sedimentation, filtration and GAC, postchlorination, fluoridation, and pH adjustment with lime (Figure A-50).

Davenport's taste and odor problems were chronic before 20 gravity sand filters were converted to granular carbon in 1973. Algae blooms, upstream industrial pollution, agricultural runoff, and accidental spills are the major sources or organic contaminants that contribute to taste, odor, and turbidity problems at Davenport. The plant must also contend with trihalomethanes.

The initial 1973 GAC installation, which eliminated the need for continued PAC (except as backup in emergency situations), had a filter-bed depth of 6 in. sand and 18 in. GAC. In 1975, GAC in the 20 plant filters was replaced for the first time and new carbon installed to the total depth of 24 in. Then, in 1978, Davenport Water signed a 3-year contract with AWWS Company that specified periodic changeout of used carbon and various analytical and monitoring services.

Filtration rate at Davenport is 2 gpm ft^2. Carbon contact time is 7.5 min. Individual filters are backwashed every 24 hr.

SYSTEM OPERATION AND PERFORMANCE

The GAC installation at Davenport is aimed primarily at taste and odor control. A secondary benefit is THM (trihalomethane) reduction.

It appears that the time span in which GAC will remove THM can be measured in months or years at the Davenport water treatment facility. Research by EPA, the American Water Works Association, and other groups on the adsorptive capacity of granular carbon for THM had indicated that removal of THM by GAC is shortlived, measured in weeks. Therefore, it was of great interest to find the results at Davenport illustrated in Table A-51. The THM reduction of 23 and 31 percent was achieved by an activated carbon that had been on-line for more than 2 years and had processed more than 1 mil gal settled water/ft^3 GAC. To check this result further, a pilot column was loaded with the spent carbon; tests (Table A-52) again indicated a 25 percent reduction in THM.

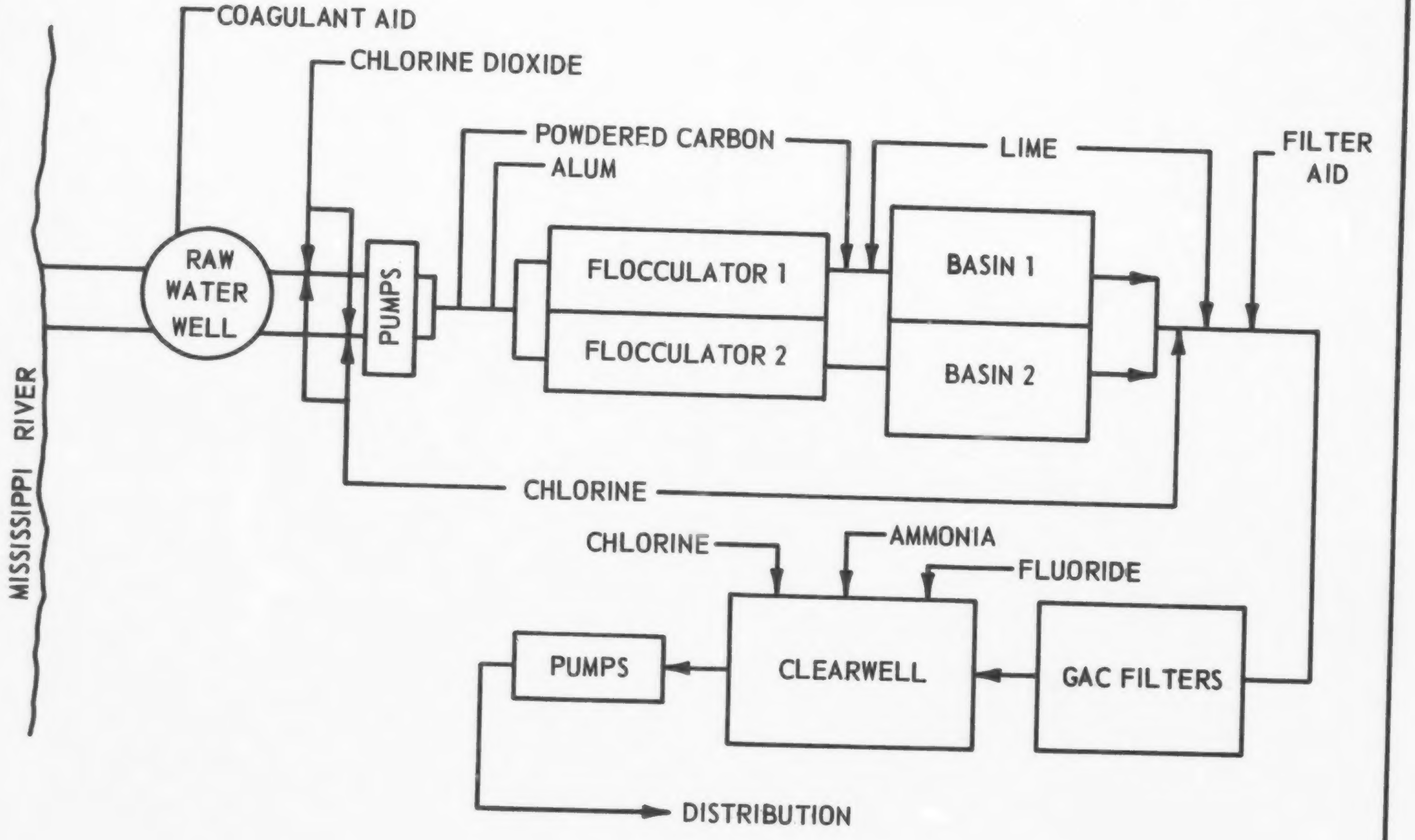
COAGULANT AID
CHLORINE DIOXIDE
POWDERED CARBON
ALUM
LIME
FILTER AID
RAW WATER WELL
PUMPS
FLOCCULATOR 1
FLOCCULATOR 2
BASIN 1
BASIN 2
MISSISSIPPI RIVER
CHLORINE
CHLORINE
AMMONIA
FLUORIDE
PUMPS
CLEARWELL
GAC FILTERS
DISTRIBUTION

Figure A-50. Flow diagram, Davenport Water Co., East River Station (AWWS Co.), Davenport, IA.

The granular carbon in the 20 plant filters was changed in July and August of 1978, and the percentage of THM reductions then ranged from a high of 60 percent to a low of 19 (Tables A-51 and A-53).

Use of granular carbon at Davenport also has helped reduce need for chlorine. Specific types of organics that exhibit chlorine demand are effectively removed by GAC. This reduces chlorine demand and allows for easier maintenance of chlorine residuals. At Davenport, chlorine feed has been reduced by 18 percent over a 5-year period.

TABLE A-51. TRIHALOMETHANE REMOVAL AT DAVENPORT WATER COMPANY

		Trihalomethanes, µg/L					
Date 1978	Location	$CHCl_3$	$CHBrCl_3$	$CHBr_2Cl$	$CHBr_3$	TTHM	Reduction %
5/8	Settled water effluent basin 1	93	4	<1	<1	97	
5/8	Settled water effluent basin 2	97	4	<1	<1	101	
5/8	Plant effluent	71	3	<1	2	76	23
7/20	Settled water basins 1 and 2	104	5	<1	<1	109	
7/20	Filter 2 GAC*	73	2	<1	<1	75	31
7/20	Filter 9 PWS†	42	1	<1	<1	43	61
7/20	Plant effluent	42	2	<1	<1	44	60

*Calgon FS 400
†Potable Water Service

TABLE A-52. PILOT COLUMN TEST EXHAUSTED GAC, DAVENPORT WATER COMPANY

		Trihalomethanes, µg/L					
Date 1978	Location	$CHCl_3$	$CHBrCl_2$	$CHBr_2Cl$	$CHBr_3$	TTHM	Reduction %
10/10	Mississippi River water	12	<1	<1	<1	12	
10/10	Settled water effluent basins 1 and 2	107	2	<1	<1	109	
10/10	Pilot column effluent	81	1	<1	<1	82	25

*Calgon FS 400

TABLE A-53. TRIHALOMETHANE REDUCTION AFTER GAC CHANGE, DAVENPORT WATER COMPANY

		Trihalomethanes, g/L			
Date	Filter Location	Quenched	Potential	End	Reduction %
Nov.	Influent	152	87	239	
1978	Effluent	120	15	135	44
Dec.	Influent	93	56	149	
1978	Effluent	97	8	105	30
Jan.	Influent	71	26	97	
1979	Effluent	62	7	69	29

Davenport also realized a significant savings in backwash water. With sand used as a filter medium, 15 to 17 gpm/ft^2 of finished water is needed for backwashing. With GAC, however, the maximum backwashing requirement has been 14 gpm/ft^2. This translates into a 15 percent backwash-water reduction over a 5-year period.

Another benefit of granular carbon as used at Davenport is that removal of turbidity is improved. Raw water turbidities fluctuate from 0 NTU to highs of 150 to 200 NTU at other times. Normal levels are in the range of 18 to 20 NTU. In the treatment process, most solids are settled out by sedimentation using cationic polymers to help coagulate the solids. By the time the water reaches the GAC filters, turbidity levels are generally less than 3 NTU; after passing through the GAC, the polished water is at a level of 0.32 NTU.

Because of a strong soil conservation program on the farmlands north of Davenport, the amount of naturally occurring clays and other suspended solids in the Mississippi River has decreased. This reduces turbidity in the plant's raw-water intake--which is good. Lowered turbidity in the river, however, allows more sunlight and more heat to penetrate the river and cause more heat- and light-sensitive algal bloom. Thus, reduced turbidity can result in greater taste and odor problems at the Iowa plant.

Removal of TOC at Davenport confirms the experience elsewhere--TOC removals do not correlate with specific organic removals. This is illustrated by Tables A-54 and A-55. Table A-55 also shows the decrease in TOC removal with time of GAC service.

The cost of using powdered and granular carbon were compared; over a 3-year period. Davenport's management estimates it saved 24 percent by using GAC instead of PAC ($5.18 mil gal of finished water produced). Also, GAC is thought to do a better job of controlling taste and odor than does PAC. Unlike PAC treatment, which must be constantly adjusted to compensate for changing water conditions, granular carbon treatment requires no changes once it is in place. Due to GAC's reserve adsorption capacity, emergency treatment responses to sudden shifts in water quality are unnecessary.

TABLE A-54. ANALYSIS OF ORGANICS AT THE DAVENPORT WATER COMPANY, OCTOBER 7, 1976*

Compound	Concentration g/L Influent	Concentration g/L Effluent
Alkane	0.3	0.2
Alkyl benzene	0.2	ND†
Benzothiazole	4.2	ND
1 - Butyne	0.1	ND
1 - (Chloroethyl) toluene	0.1	ND
Chloroform	120	12
1,3-Dichloropropanone	0.2	ND
4,4-Dimethyl-1-pentene	0.2	ND
Isoprene	1.7	0.6
Naphthalene	2.0	ND
TOC	--	16000

*Carbon in service: 10 months; †Water processed: 0.391 mg/ft^3.

TABLE A-55. GRANULAR ACTIVATED CARBON REMOVAL OF TOC AT THE DAVENPORT WATER COMPANY, NOVEMBER 1978--MAY 1979

Month of operation	Concentration g/L* Influent	Concentration g/L* Effluent	Removal, %
4	6560	5190	20.9
5	7000	5100	22.9
6	5475	4775	12.8
7	3960	3750	5.3
8	4250	4000	5.9
9	4000	3550	11.3
1	5900	2750	53.4

*Average of 2 to 4 samples per month.

Just before its 1973 GAC installation, Davenport experienced threshold odor numbers (TON) of 8 to 10 in influent water. At the time, plant personnel relied on powdered activated carbon (PAC) and sand filtration for control. A significant taste and odor reduction followed the GAC installation, despite increased organic loadings in 1975 when new chemical plants went on-stream north of Davenport (Table A-56).

Based on previous PAC operation at Davenport, management has concluded that GAC gives more uniform results and is easier to handle.

TABLE A-56. TASTE AND ODOR REDUCTION FOLLOWING GAC USE

Year	Influent, TON	Effluent, TON
1973-74	4.0 "Musty"	<1
1975 (First GAC changeout)	3.5 "Musty"	1.5-2
1976	4.5 "Musty"	<1
1977	5.0 "Musty"/"Grassy"	2
1978 (Second GAC changeout)	5.5 "Musty"	<1

Recently, Davenport plant operators developed a system to complete the unloading of carbon from the truck (with hoppers and eductors) to the filter in just 2 1/2 hr, and to load spent carbon back into the truck in just 2 hr per filter. The system makes use of a 1,400 gpm pump and a fire hydrant pressured to 120 psig to pipe the carbon slurry.

Davenport modified a 3-in. sand eductor and found that it could take the carbon out of the filter without putting a man in. During carbon removal, the eductor is kept flooded at all times by introducing backwash water. The backwash water keeps the carbon moving in a slurry. It flows downward and inward toward the mouth of the eductor, which creates a vacuum effect. The appearance is like that of a miniature volcano. This new operation requires just two men (a 50 percent reduction).

Use of GAC at the Davenport Water Company has produced effluent TON consistently less than one; a THM in the effluent of less than 100 ppb; and effective filtration of turbidities (to less than 1 NTU).

In taste and odor control, the primary function of the GAC installation, the following results have been achieved;

1. A saving in backwash water and an increase in saleable water.
2. A 16.2 percent reduced overall cost for taste-and-odor control.
3. Clean, simple operation that requires no adjustments as the level of raw water taste and odor changes.

The 1980 contract between the carbon supplier and the Davenport Water Company calls for replacing the GAC in all 20 filter units--10 in the spring and the other 10 in the fall. Based on the average daily water use of 18 mil gal and a contract cost of $11,000 per month for 1980, the operating cost of GAC treatment for taste-and-odor control plus side benefits is 2¢/1000 gal.

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Blanck, C. A., "GAC Value Exceeds Expectation". Water & Sewage Works, January, 1980.

Plant inspection; information provided by Clarence A. Blanck and Don Wulf of AWWS Co.

CASE HISTORY NO. 22
SPRECKLES SUGAR DIVISION
AMSTAR CORPORATION
WOODLAND, CALIFORNIA
SUGAR REFINERY

HISTORY AND INTRODUCTION

The Woodland, California, sugar factory of the Spreckles Sugar Division, Amstar Corporation, one of five Spreckles sugar factories, began manufacturing granulated sugar from sugar beets in 1937.

Harvesting of sugar beets near Woodland begins in July or August and continues until the rains begin in November or December. The harvest of overwintered beets resumes in March after the rains and continues for 80 to 90 days. The Woodland factory fall and spring campaigns correspond to the fall and spring beet harvests. The factory, which has a processing capacity of 3,450 tons of beets/day, maintains beet storage capacity for only 5 to 7 days of normal operation since beet quality starts to deteriorate soon after harvesting.

When beets arrive at the factory, they are prepared for processing by trash separation and washing. Sugar beet processing includes slicing, diffusion (leaching of sugar from the pulp), purification, evaporation, and crystallization. Valuable by-products of sugar beet processing include molasses and dried pulp, which are used in animal feed.

The GAC adsorption process is used in beet sugar refining to remove both color and other impurities that would otherwise cause the formation of floc in the sugar solution.

The Woodland factory was the first of the Spreckles Sugar plants to install a GAC facility for removing color and floc from beet sugar thick juice. This facility uses the patented* Continuous Adsorption Process (CAP), which was installed in 1958.

DESIGN OF GAC SYSTEMS

Adsorption System Design

The following is the design basis for the Woodland Factory adsorption system.

Number of adsorbers	Three
Size (each)	9-ft 6-in. diameter x 47-ft 6-in. high
Mode of operation	Upflow expanded, parallel
Carbon bed depth	31 ft
Type and size of carbon	Granular, 12 x 40 mesh
Quantity of carbon (each)	62,000 lb

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*U.S. Patents No. 2,954,305; 2,769,297; and 2,969,298 assigned to the American Sugar Refining Company.

Each of the three adsorption columns is cylindrical with an 8-ft high inverted cone bottom section, which has a 60° slope. The cylindrical section of each is epoxy lined and the cone bottoms are stainless steel coated. Temperature control in the column is provided by steam tracing, insulation, and aluminum jacketing.

Factory thick juice (beet sugar juice after diffusion, purification, and partial evaporation) containing color and floc is injected into each adsorber via nozzles located near the bottom of the vertical cylindrical section and flows upward to the top where the clear sugar liquor discharges over a weir. Fresh activated carbon is continuously added at the open top of each adsorber and exhausted carbon is continuously removed at the bottom; this results in a continuous counter-current process. The process is carefully controlled so that the carbon beds are maintained in a slightly expanded (not fluidized) condition. To maintain expansion, the flow rate, the sugar solids concentration, and the temperatures are carefully controlled. The thick juice is kept at 90°C and 60-65 Brix.

Carbon fines and other particulate material that may be contained in the decolorized sugar liquor are removed by filtration in plate-and-frame filters after adsorption. A schematic flow diagram of the adsorption system is shown in Figure A-51.

In the continuous adsorption process, the activated carbon in the lower part of the adsorber is exposed to the highest concentration of color and floc in the thick juice. As it adsorbs more of the impurities it moves downward by gravity into the cone section and finally exits the adsorber at the apex of the cone. The spent carbon then flows in a sugar liquor slurry to the top of a sweetening-off column adjacent to the adsorbers. There steam and water are added to remove and recover a sugar that accompanies the carbon during transfer. One sweetening-off column, 24-ft high and 18-in. in diameter is used for processing the spent carbon from the three adsorbers. Flow rate of the carbon is controlled by an adjustable weir at the top of the spent carbon discharge lines before entering the sweeting-off column.

Reactivation System Design

The carbon was originally reactivated in a rotary kiln. In 1962, the kiln was replaced with a multiple hearth furnace in an effort to reduce carbon losses and improve reliability of the reactivation system.

The design basis for the present reactivation furnace is:

Furnace type	Multiple hearth
Furnace size	8-ft 4-in. x six hearth
Furnace capacity (design)	15,000 lb/day
Fuel	Natural gas

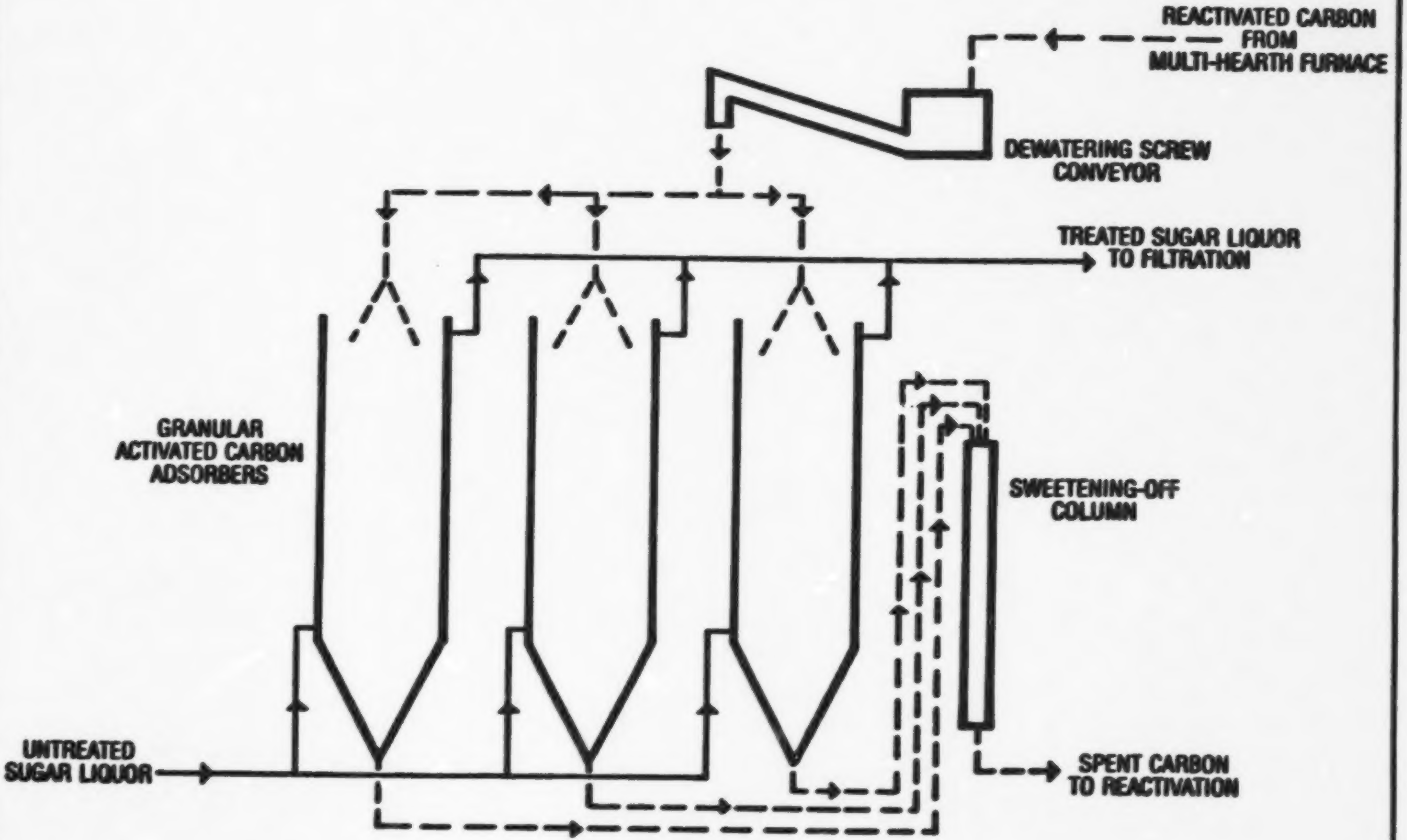
REACTIVATED CARBON FROM MULTI-HEARTH FURNACE
DEWATERING SCREW CONVEYOR
TREATED SUGAR LIQUOR TO FILTRATION
GRANULAR ACTIVATED CARBON ADSORBERS
SWEETENING-OFF COLUMN
UNTREATED SUGAR LIQUOR
SPENT CARBON TO REACTIVATION

Figure A-51. Schematic flow diagram of granular activated carbon adsorption system, Amstar Corp.

The desweetened spent carbon flows by gravity in a water slurry to the reactivation system shown in Figure A-52.

Spent carbon slurry is discharged into the low end of an inclined dewatering screw conveyor and is moved up the inclined conveyor toward the reactivation furnace. As the carbon moves gradually upward, excess slurry water is drained off. A sufficiently high water level is maintained at the lower end of the dewatering screw to keep a water seal on the furnace to prevent excess air from entering or combustion gases from escaping from the furnace.

The dewatered spent carbon, containing about 50 perent moisture by weight, falls from the discharge end of the dewatering screw onto the upper furnace hearth for drying. From there the spent carbon is rabbled through the furnace where it increases in temperature as it falls to the lower hearths. Three gas burners located on Hearth No. 4 and three on Hearth No. 6 provide heat for drying, pyrolizing, and reactivating the carbon. To prevent combustion of the hot carbon, excess air is not allowed to enter the furnace. Steam is added at the fired hearths to assist in the reactivation process.

Hot reactivated carbon drops from the bottom hearth (No. 6) into a water-filled quench tank from which it is educted in a water slurry to a dewatering screw conveyor (similar to the spent carbon dewatering screw), located in a headhouse above the adsorbers. Excess slurry water is drained from the carbon before it is returned to the adsorbers via belt conveyors.

Off gases from the reactivation furnace (800° to 900°F) pass through a water scrubber before being discharged to the atmosphere.

OPERATION AND MAINTENANCE

The adsorption system is controlled to provide 20 to 30 min conntact time in the adsorbers and to maintain the carbon bed in an expanded condition.

Although the adsorbers were designed to contain 31-ft deep carbon beds, it was found by experience tht they could be operated as efficiently at shallower depths thereby reducing the activated carbon inventory. The adsorbers are now operated with 13 to 14 ft of carbon above the inlet nozzles. Residence time for carbon in the adsorbers is 4 to 5 days and is varied as necessary to prevent carryover of floc or color in the treated sugar liquor.

Control of the reactivation process is based on the apparent density in g/cc and iodine number of the reactivated granular carbon. These tests are run daily during the campaign. Average values for apparent density and iodine number for the 1979 fall campaign (July-December) are shown in Table A-57.

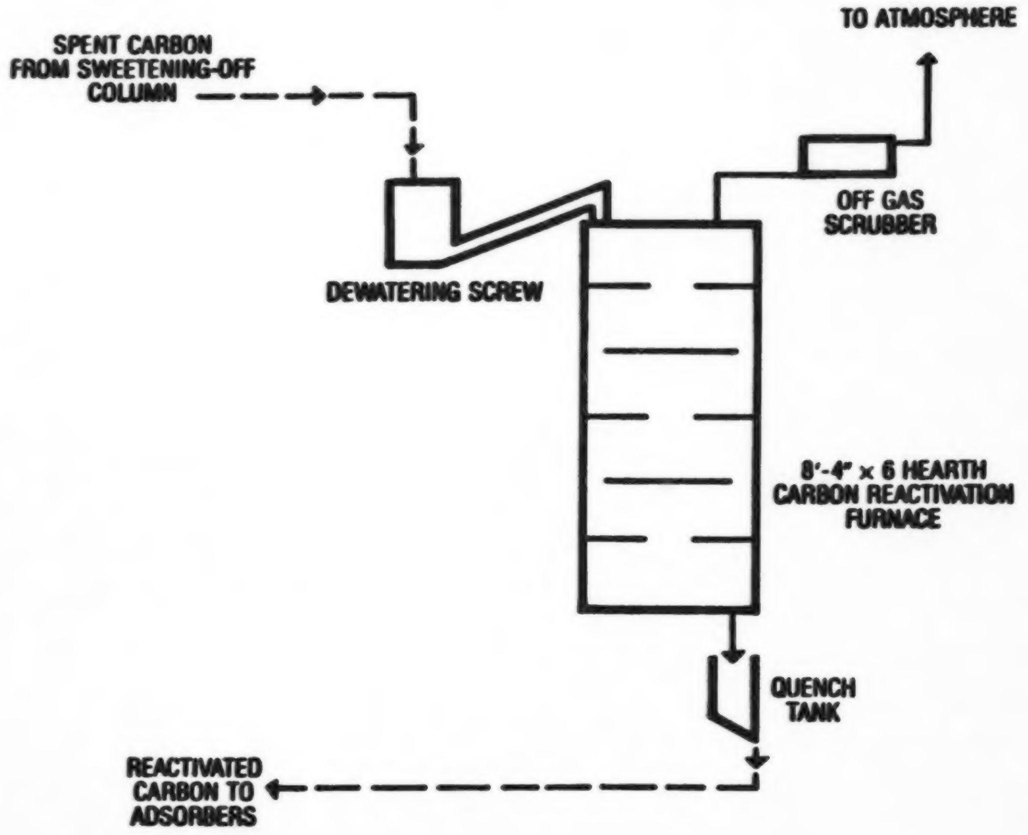
SPENT CARBON
FROM SWEETENING-OFF
COLUMN
TO ATMOSPHERE
DEWATERING SCREW
OFF GAS
SCRUBBER
8'-4" x 6 HEARTH
CARBON REACTIVATION
FURNACE
QUENCH
TANK
REACTIVATED
CARBON TO
ADSORBERS

Figure A-52. Schematic flow diagram of granular carbon reactivation system, Amstar Corp.

TABLE A-57. ACTIVATED CARBON QUALITY

Granular carbon	Apparent density g/cc	Iodine no.
Virgin	0.453	1091
Spent	0.521	250
Reactivated	0.43	516

The reactivation furnace is operated to produce reactivated carbon with an apparent density essentially equal to that of virgin activated carbon. Operating temperatures on the lower three hearths are typically 1660°, 1600°, and 1720°F at hearths 4, 5, and 6, respectively. Steam is added at hearths No. 4 and 6 (the fired hearths) at a rate of 0.25 to 0.5 lb steam/lb carbon.

Make-up carbon (virgin GAC) is added to the adsorbers at an average rate of 720 lb/day. Based on a furnace operating rate of 15,000 lb/day, carbon losses are 4.8 percent/cycle.

Scrubbing of the reactivation furnace off-gases before discharge to the atmosphere has resulted in continuous compliance with air quality requirements.

Major maintenance of the GAC adsorption system has been limited to replacement of the epoxy (Plasite) linings every 3-years.

Reactivation system maintenance has included replacement of the furnace shell in 1975 and other periodic, minor repairs. Although no major internal furnace damage has occurred such as collapse of a hearth, occasional repair and replacement of refractories has been necessary.

Since the plant operates 24 hours/day, 7 days/week during the beet processing campaigns and shuts down between them, most of the required maintenance is performed during the shutdown periods.

CAPITAL AND OPERATION AND MAINTENANCE COSTS

Capital Cost

The GAC adsorption and reactivation system as originally designed and installed, including a used rotary kiln reactivation furnace, was built in 1958 at a cost of $238,000. Included in that cost was the initial carbon fill at $53,000.

No capital cost figures are available for the existing multiple hearth furnace built in 1962 to replace the rotary kiln.

Operation Cost

Operation of the adosrption and reactivation systems at the Woodland plant requires one operator on a continuous basis. Average use of fuel, steam, and make-up carbon are:

Fuel (natural gas)	1785 Btu/lb carbon
Steam	0.25-0.5 lb/lb carbon
Make-up carbon	720 lb/day (4.8% loss)

Actual costs associated with the operation and maintenance of these systems are considered proprietary by Spreckles and are not available for publication.

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